Effect of auditory notification on sedentary behavior in office workers

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Recent research findings suggest connections between sedentary behavior, i.e. sitting, and various health risks. These findings indicate that not only the total amount of sitting is of importance, but likewise the duration of uninterrupted sitting, i.e. the duration of each sitting bout. The purpose of this research was to develop a device that could emit notifications in order to avoid long sitting bouts. The idea for the device was based on the sitting pad previously developed by Ryde and Gilson, a cushion that could be placed on a chair and detect sitting. After successful implementation of the device, it was evaluated with two participants during a period of two weeks each. During the first week it was used without notifications in order to gain baseline data about sedentary behavior. The baseline data was then compared to data from the second week with auditory notifications after 25 minutes of continuous sitting. As a result, participants increased the occurrence of sitting bouts shorter than 30 minutes by 17.7 and 6.5 percentage points. Thus, limited evidence suggests that the developed device is effective in changing sedentary behavior.

Key words: Sedentary behavior, Sitting, Workplace, Office, Sedentary awareness

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1 Introduction

Recent research findings indicate that sedentary behavior, i.e. sitting, has negative impacts on well-being and health, independent from physical activity levels. Furthermore, research suggests that not only the total sedentary time has an influence on well-being and health, but that similar associations can be made in regards to the manner of accumulating sedentary time, i.e. the length of single bouts of uninterrupted sitting (Healy et al., 2008, p. 661). These findings are especially important as large numbers of office workers spend a considerable share of their workday sitting.

A variety of interventions has been developed to reduce sedentary behavior to this day. They include the usage of sit-stand desks and workstations, educational approaches, and multi-component interventions. Another intervention approach is the sitting pad (Gilson et al., 2016) that combines an automatic detection of sitting time with prompts to remind of standing up after prolonged bouts of sitting. However, these prompts are delivered on the computer screen and can thus only be successful when the person works at the computer. Therefore, the purpose of my research is to modify the idea of the sitting pad by delivering notifications to remind of standing up through the sitting pad itself. This includes developing a functional prototype of the sitting pad with a reliable sensor to detect sitting. A means of delivering notifications is then added to this prototype. The prototype is finally evaluated as an intervention strategy to reduce sedentary behavior. In order to measure the success of this intervention, the duration of sitting bouts with and without the notifications are compared. This procedure is expected to offer insights into the effectiveness of the sitting pad to change sedentary behavior.

First, this thesis provides an overview of literature regarding physical activity, sedentary behavior and their health impacts. Furthermore, it introduces means of measuring sedentary behavior. Additionally, interventions targeting sedentary behavior are presented and contrasted. Chapter 4 describes the design considerations for modifying the sitting pad. As a next step, the implementation phase is discussed. Chapter 6 presents the details of planning and conducting both the pilot studies and the major study including an overview of results. Subsequently, these results are discussed and hints for future research are provided. Finally, conclusions are drawn.

2 Literature Review

2.1 Overview

Research has demonstrated the health benefits of physical activity and established recommendations for physical activity are in place. Recent findings suggest, however, that sedentary behavior, i.e. sitting, has an impact on well-being and health independent from physical activity levels. Current research focuses on deepening the understanding of sedentary behavior and its health effects in order to develop recommendations on sedentary behavior. Furthermore, a deeper understanding of sedentary behavior allows for the development and evaluation of intervention strategies.

This chapter defines sedentary behavior and distinguishes it from physical activity. Furthermore, the health effects of sedentary behavior and physical activity are evaluated without examining the medical details. Additionally, an overview of the recommendations for sedentary behavior and physical activity is given. Finally, the chapter presents means of measuring sedentary behavior, both through subjective and objective methods.

2.2 Sedentary Behavior and Physical Activity

Sedentary behavior is commonly defined as “behaviors that involve sitting and low levels of energy expenditure, typically less than 1.5 metabolic equivalents (METs)” (Marshall & Ramirez, 2011, p. 519). “One MET is the energy cost of resting quietly, often defined in terms of oxygen uptake as 3.5 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$” (Pate, O’Neill, & Lobelo, 2008, p. 174). Thus, MET represents the “ratio of physical activity metabolic rate to resting metabolic rate” (Owen et al., 2000, p. 156). Based on this definition, sedentary behavior includes “activities such as sleeping, sitting, lying down, and watching television, and other forms of screen-based entertainment” (Pate et al., 2008, p. 174). However, this wide range of included behaviors is somewhat conflicting with the etymology of the word ‘sedentary’, which is derived from Latin and means ‘to sit’ (Smith & Biddle, 2008, p. 6). Similarly, Marshall and Ramirez (2011) argue that due to the small number of behaviors that “involve both sitting and energy expenditure >1.5 METs, sedentary behavior is best operationalized as sitting” (p. 520). Of course sleeping as a sedentary behavior constitutes a large part of daily time expenditure. However, it is usually not targeted by interventions on physical activity and sedentary behavior (Marshall & Ramirez, 2011, p. 520). As this research examines sedentary behavior only as sitting, the term is limited to sitting.

Physical activity is defined as “any bodily movement produced by skeletal muscles that results in energy expenditure” (Caspersen, Powell, & Christenson, 1985, p. 126). Based on energy expenditure, the intensity of physical activity is often classified as light, moderate, or vigorous (Garber et al., 2011, p. 1336) as shown in Figure 1.

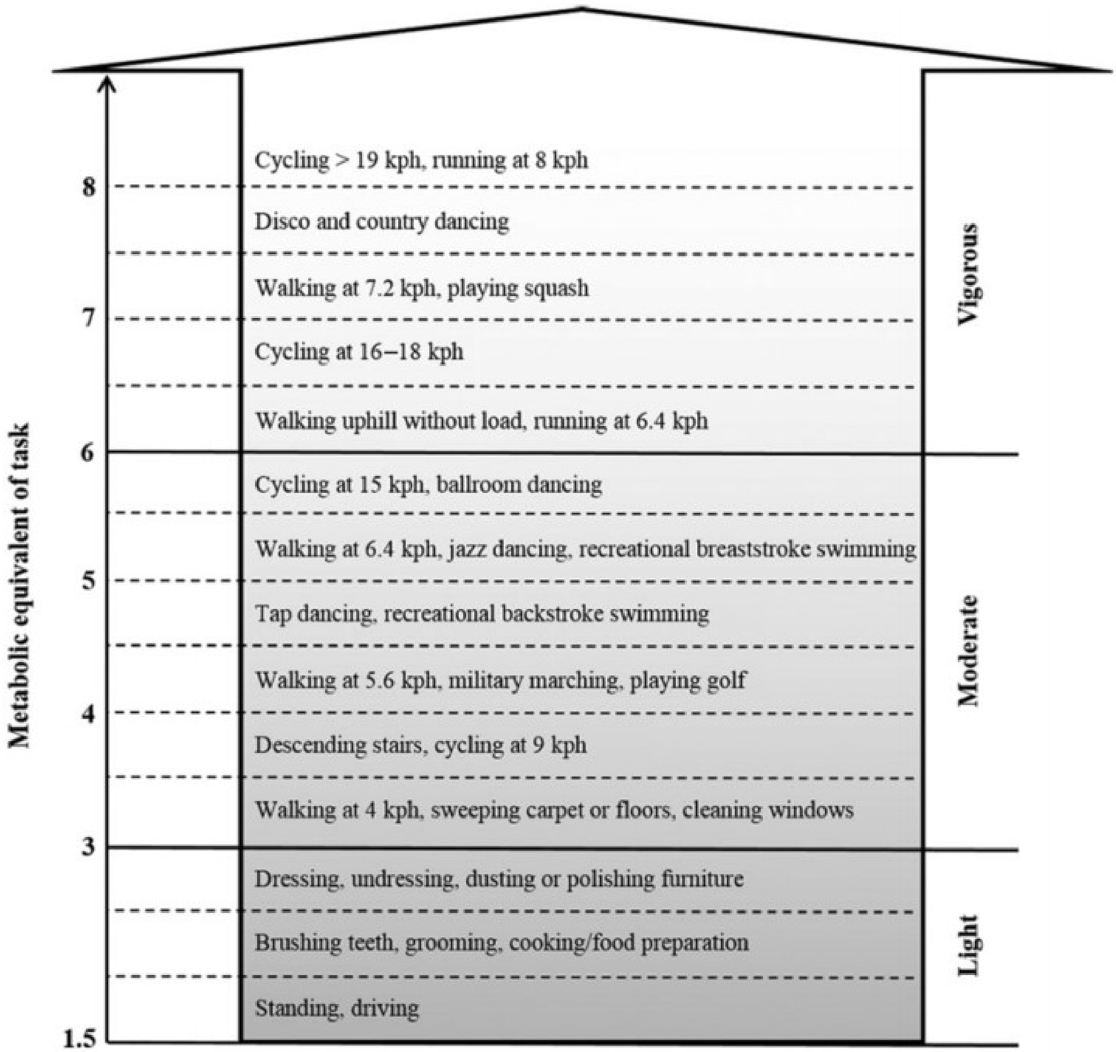

Figure 1: Light, moderate and vigorous intensity physical activities
(Cavalheri, Straker, Gucciardi, Gardiner, & Hill, 2015, p. 2)

Oftentimes, sedentary behavior is used as a synonym for physical inactivity (Smith & Biddle, 2008, p. 6). Thus, individuals who do not meet recommendations for moderate-to-vigorous physical activity (MVPA) are classified as inactive or sedentary (Marshall & Ramirez, 2011, p. 519). However, Marshall and Ramirez argue that sedentary behavior should be treated as a distinct class of behavior in order to avoid the assumption that "sedentary behavior and MVPA [are] opposite ends of the same continuum" (2011, p. 519). Thus, "*too much sitting* […] may be seen as distinct from *too little exercise*" (Owen, 2012, p. 535). Owen et al. (2000, p. 156) introduced the idea that sedentary behavior may have harmful effects on health such as overweight and obesity. They assumed these health risks to be independent from leisure-time physical activity levels. Their position was based on a study conducted among Australian adults that associated long hours of television viewing with a high body mass index despite high levels of activity in their leisure time (Owen et al., 2000, p. 157). Thus, sedentary behavior is assumed to be linked with "specific determinants and effects on disease risk, separate from the behavior of leisure exercise" (Marshall & Ramirez, 2011, p. 519). Apart from these associations between health risks and *total* sedentary time, it is assumed that similar associations can be made in regards to the manner of accumulating sedentary time, i.e. the length of single bouts of uninterrupted sitting (Healy et al., 2008, p. 661).

Currently, it is widely accepted to treat sedentary behavior as a distinct class of behavior. This is underlined by the fact that the 2011 issue of the report 'Start Active, Stay Active' (Chief Medical Officers, 2011, p. 34) included non-quantitative recommendations on sedentary behavior for the first time. Furthermore, the 'Physical Activity Statistics 2012' report by the British Heart Foundation (Townsend et al., 2012) contains detailed data about sedentary behavior, which highlights the importance of the issue.

While sedentary behavior is treated as a distinct class of behavior based on its health outcomes, it can be viewed as a subdomain of physical activity in terms of energy expenditure (Smith & Biddle, 2008, p. 8). Therefore, the five characteristics of physical activity apply likewise to sedentary behavior. According to Smith & Biddle (2008, p. 8) these characteristics are the following.

- Frequency: "number of times the physical activity is performed within a specific time period (e.g., bouts per week, month, or year)"
- Intensity: "magnitude of the physiologic response to physical activity and is often quantified by the amount of metabolic work performed (e.g., kilocalories expended)"
- Duration: "length of time (usually in minutes) the activity is performed"
- Type: "features of the behavior itself (e.g., walking, jumping, running)"
- Domain: "the context or setting in which physical activity occurs (e.g., at school, during leisure time, for transportation)"

These characteristics and their combination possibilities underline that sedentary behavior has many facets. Therefore it needs to be assessed in more detail than focusing only on duration, i.e. total sedentary time (Atkin et al., 2012, p. 1463). Furthermore, the many facets of sedentary behavior increase the difficulty of comparing research findings in the domain (Smith & Biddle, 2008, p. 8).

Many changes have led to reduced human energy-expenditure. These include changes in the physical, economic, and social environments (Owen, 2012, p. 535). Especially changes in technologies for personal transportation, communication, workplace productivity, and domestic entertainment have contributed to this phenomenon (Owen, 2012, p. 535). A study among women in the US revealed an increase of screen-based media use from 8.3 hr/week in 1965 to 16.5 hr/week in 2010 (Archer et al., 2013, p. 4).

Likewise, DeMattia, Lemont and Meurer (2007, p. 69) remind that the introduction of cable, video games and the internet have increased sedentary behaviors. However, numbers from the U.S. Bureau of Labor Statistics indicate that people in full-time employment spend on average only two hours per day watching TV and playing (computer) games, while on weekdays they spend 9.2 hours per day at work with a large proportion of sitting (van Uffelen et al., 2010, p. 380). For Canada, it is estimated that the average adult spends 9.5 hours per day being sedentary, with most of it sitting (Colley et al., 2011, p. 6). Furthermore, figures of objectively measured activity levels from the UK indicate that men spend 600 minutes being sedentary on weekdays and 579 minutes on weekend days (Townsend et al., 2012, p. 100). According to the same source, women spend slightly less time being sedentary with 592 minutes on weekdays and 563 minutes on weekend days.

Van Uffelen et al. (2010, p. 380) remind that occupational sitting represents a large share of overall sitting time especially for full-time employees in physically inactive jobs. According to figures from Buckley et al. (2015, p. 2), office workers spend 65–75% of their working hours sitting with more than 50% in prolonged periods of sustained sitting. The large number of people that work in physically inactive jobs underlines the importance of further research in occupational sedentary behavior.

2.3 Sedentary Behavior and Health

The health risks of physical inactivity have been proven. According to the World Health Organization (2009), it is one of the leading global risks for mortality accounting for six percent of deaths globally. Furthermore, it is known that regular physical activity has many benefits on psychological health and well-being while reducing the risk of coronary heart disease, stroke, type 2 diabetes, osteoporosis, some cancers and depression (Chief Medical Officers, 2011, p. 32)

On the other hand, there has been less research on the health risks of sedentary behavior compared to those resulting from a lack of physical activity (Van der Ploeg, Chey, Korda, Banks, & Bauman, 2012, p. 494). Some research has indicated that sedentary behavior leads to poor health independent of age and overall physical activity levels (Townsend et al., 2012, p. 100). According to Owen (2012, p. 536) it supports the development of major chronic diseases. Two large (n=222,497 and n=240,819) questionnaire-driven studies from Australia and the US revealed associations between sedentary behavior and all-cause mortality in adults independent of physical activity levels (Matthews et al., 2012, p. 437; Van der Ploeg et al., 2012, p. 494). The US study assessed sedentary behavior based on television viewing and overall sitting. According to Owen et al. (2000, p. 156) it is common practice in research to study sedentary behavior based on television viewing due to its high prevalence.

Despite the numerous studies that have established an association between sedentary behavior and health risks, one study in 2008 claimed that “most studies have not [truly] measured sedentary behavior or differentiated it from light activity” (Pate et al., 2008, p. 173). This study suspected that much of the conducted research uses the former definition of sedentary behavior, which looks at it as a synonym of physical inactivity as described in Section 2.2. Furthermore, it claimed that sedentary behavior is usually investigated through proxy behaviors such as television viewing instead of measuring it directly (Pate et al., 2008, p. 173). The authors admitted that these studies have contributed to the knowledge about health outcomes of regular exercise, however not to the effects of sedentary behavior (Pate et al., 2008, p. 138). Based on a detailed analysis of various previous studies, the authors confirmed their claim. Furthermore, a systematic review of studies established that there is only limited evidence associating occupational sitting and health risks (van Uffelen et al., 2010, p. 379). Their review included 43 studies with a focus on the following health risks: Body Mass Index, cancer, cardiovascular disease, diabetes mellitus, and mortality. 22 studies found “that occupational sitting was associated with an increased health risk”, 20 found “that there was no association”, and 5 found “that sitting was associated with a decreased health risk” (van Uffelen et al., 2010, p. 382). The authors conclude, however, that due to the different nature of the studies, it is difficult to draw definitive conclusions. Another, more recent, systematic review on the health outcomes of sedentary behaviors in adults reaches a similar conclusion by suggesting that causal relationships can only be clarified through additional studies of high methodologic quality (Proper, Singh, van Mechelen, & Chinapaw, 2011, p. 174). Nonetheless, based on the rise of sedentary behaviors due to technology, the authors recommend reducing sedentary time and increasing physical activity levels (Proper et al., 2011, p. 181).

2.4 Recommendations for Physical Activity and Sedentary Behavior

Some recommendations for physical activity have been established. According to the World Health Organization (2009, p. 36), it is advisable to engage in 2.5 hours of moderate-intensity activity or 1 hour of vigorous activity per week in order to achieve health benefits.

Thus far, there is no universally accepted quantitative recommendation on the daily sedentary time in order to stay healthy. The 2011 report ‘Start Active, Stay Active’ claims that the current scientific evidence is not sufficient to develop quantitative recommendations on sedentary behavior in order to stay healthy (Chief Medical Officers, 2011, p. 34). However, the report recommends reducing total sedentary time and avoiding extended sitting periods (Chief Medical Officers, 2011, p. 34). Likewise, the American College of Sports Medicine recommends the reduction of total sedentary time in their Position Stand on Guidance for Prescribing Exercise (Garber et al., 2011, p. 1334). In 2015, an international group of experts was asked to develop guidelines for employers in regards to sedentary work. Their recommendation for predominantly desk based workers is to aim at a total of two hours per day of standing and light activity in the beginning. Gradually, this should be increased to four hours per day (Buckley et al., 2015, p. 1). This is aligned with previous research that found reduction in fatigue and musculoskeletal discomfort by substituting 4 hours of sitting with standing during each workday (Thorp, Kingwell, Owen, & Dunstan, 2014, p. 765). However, the authors suggest that broader benefits can be achieved through regular standing breaks during the workday. Compared to seated work, one study revealed that such breaks do not have an impact on productivity (Thorp et al., 2014, p. 765). It examined the "short-term (5-day) effect of replacing workplace sitting time with routine 30 min bouts of standing […] in overweight/obese, but otherwise healthy, office workers" (Thorp et al., 2014, p. 766). Other studies suggest that it is possible to generalize these findings to the broader working population. Healy et al. (2008) revealed associations between breaks in objectively-measured sedentary time and metabolic outcomes. These associations were independent of total sedentary time, moderate-to-vigorous intensity time, and mean intensity of the breaks. Buckley et al. (2015, p. 2) demonstrated that "avoiding long periods of sitting coupled with even short but frequent sessions of more light-intensity movement improves glucose and insulin levels." However, no quantitative recommendations on regular standing breaks could be identified.

Apart from reducing overall sedentary time and introducing regular standing breaks, postural variation during the workday plays an important role. Postural variation is any change in body position. It has demonstrated benefits on musculoskeletal health, reduced physical complaints, and decreased fatigue (Straker, Abbott, Heiden, Mathiassen, & Toomingas, 2013, p. 518). However, it is difficult to define recommendations on postural variation.

2.5 Measuring Sedentary Behavior

As discussed in the previous sections, the health risks of physical inactivity are established and widely accepted recommendations on physical activity exist. However, more research is required on the health risks of sedentary behavior and quantitative recommendations need to be developed. Atkin et al. (2012, p. 1461) remind that "high-quality exposure assessment is essential to identify causal associations with health outcomes, to quantify precisely the magnitude of the association and to describe dose–response relationships." Based on the same reasoning, van Uffelen et al. (2010, p. 386) recommend a quantification of sitting duration in future studies. Therefore, this section gives an overview of the different means of measuring sedentary behavior.

As established above, sedentary behavior is a distinct class of behavior based on its implications on health. However, it can be viewed as a subdomain of physical activity in terms of energy expenditure (Smith & Biddle, 2008, p. 8). Therefore, many of the measurement methods of physical activity can be applied in measuring sedentary behavior.

Sedentary behavior has been measured since the 1960s (Archer et al., 2013) using subjective measurement methods. These methods measure sedentary behavior through self-report such as questionnaires (self-administered as well as in-person and telephone interview) and diaries (Atkin et al., 2012, p. 1461). However, these measures show only moderate reliability and slight to moderate validity (Atkin et al., 2012, p. 1460). Owen et al. (2000, p. 156) point out that subjective measurement methods face the challenge that sedentary behaviors are repetitive and noninteractive, which makes recall difficult. Despite these limitations, it is argued that self-report methods remain important in population-prevalence studies (Owen, 2012, p. 537). The IPAQ (International Physical Activity Questionnaire) is a subjective measurement method that has demonstrated good test-retest repeatability and acceptable validity against accelerometers in regards to measuring time spent sitting (Bauman et al., 2011, p. 229). It is concluded that the method is suitable for population-level surveillance studies to evaluate sitting time (Rosenberg, Bull, Marshall, Sallis, & Bauman, 2008, p. S39).

Sedentary behavior is increasingly measured using objective measurement methods in order to avoid some of the limitations linked to subjective measurement methods (Atkin et al., 2012, p. 1464). Quoting Healy et al. (2011, p. 220), the ideal measure of sedentary time would

- be accurate and reliable across different population groups;
- distinguish among sleeping, reclining, sitting, and standing;
- distinguish among different domains and specific behaviors;
- be low-cost, have low participant burden, and be able to be worn continuously for extended periods of time;
- and produce data that are easily analyzed and interpreted and can be provided in real time.

They conclude, however, that currently no such instrument exists. At this time, a variety of devices is available to measure sedentary behavior objectively. Accelerometers are small devices usually worn on the hip or lower back that measure the acceleration frequency and amplitude (Atkin et al., 2012, p. 1464). Since the publication of the study by Atkin et al. (2012), the importance of accelerometers has increased as they can be found in smartphones and smart watches these days. The usage of accelerometers enables "the measurement of the full range of physical activity levels, from completely sedentary to extremely vigorous" (Pate et al., 2008, p. 178). It is therefore argued that "accelerometry is emerging as a valuable tool for exploring the independent associations of various activity levels with health outcomes" (Pate et al., 2008, p. 178).

However, the usage of accelerometers has limitations such as misclassification of non-acceleration measurements (zero counts), which could be interpreted as sedentary time or non-wear time (Healy et al., 2011, p. 221). Furthermore, accelerometers assess "intensity of movement and thus are less able to distinguish between postures, such as sitting and lying or standing still" (Atkin et al., 2012, p. 1465). For this purpose posture monitors (inclinometers) were developed. Posture monitors are small devices worn directly on the skin, usually on the thighs. As they measure acceleration including the gravitational component, it is possible to gain data on time spent sitting/lying, standing, stepping, sit-to-stand transitions, and stand-to-sit transitions (Atkin et al., 2012, p. 1465). It is argued that posture monitors might have higher validity and reliability in respect to measuring sedentary behavior and thus should be used by researchers and practitioners (Martin et al., 2015, p. 8). Less common is the evaluation of sedentary behavior using heart rate monitoring. Based on the heart rate a distinction can be made between rest and exercise (Atkin et al., 2012, p. 1466).

Apart from these methods that measure sedentary behavior independent of their domain, i.e. their context or setting, it is possible to measure sedentary behavior using context specific measurement methods. One of such instruments is known as the sitting pad (Ryde, Gilson, Suppini, & Brown, 2012, p. 383). It has been developed at the University of Queensland, Australia and aims at measuring desk-based occupational sitting. This prototype instrument consists of a pressure sensor contained in a cushion that is placed on an office chair. It is able to detect and record transitions to and from sitting of greater than three seconds. Its validity was established using camera derived direct observation. Furthermore, the data produced by the sitting pad was compared with inclinometer data and it was concluded that it is a "highly accurate measure of desk based sitting time" (Ryde et al., 2012, p. 383). However, I could not identify additional independent studies on its validity. This is likely due to the sitting pad being a prototype device. Ryde et al. (2012, p. 383) suggest that the sitting pad solves some of the issues associated with objective measurement methods of sedentary behavior such as the fact that accelerometers measure movement and cannot differentiate between sitting and standing. Furthermore, they claim that inclinometers as an objective measurement method are expensive and not suitable for day-to-day use.

Healy et al. (2011, p. 225) highlight the importance of both subjective and objective measurement methods of sedentary behavior as they capture different aspects of sedentary behavior. Therefore, they recommend employing both for monitoring of sedentary time.

In conclusion, precise measurement of sedentary behavior is of importance for several reasons. First, it can help clarifying the health outcomes of sedentary behavior. Second, it can assist in designing, developing, and evaluating interventions, which is discussed in more detail in the following chapter.

3 Interventions to Avoid Health Risks from Sedentary Behavior

Since the 1990s, public health intervention strategies have mostly focused on physical activity of moderate intensity (Owen et al., 2000, p. 153). The aim of these strategies is to tackle insufficient activity levels in industrialized countries (Owen et al., 2000, p. 154). However, as shown in Section 2.2, sedentary behavior should be treated as a distinct class of behavior based on its health outcomes. Therefore, intervention strategies that focus on sedentary behavior are needed. It is possible to combine intervention strategies for sedentary behavior with intervention strategies for physical activity, thus decreasing sedentary time while increasing physical activity levels. However, a recent systematic review concluded that interventions targeting sedentary behavior alone are more effective in reducing sedentary behavior than interventions targeting physical activity alone or physical activity and sedentary behavior combined (Martin et al., 2015, p. 6). These findings differ from claims made by Marshall & Ramirez (2011, p. 526) that interventions on sedentary behavior should always target both an increase in physical activity and a reduction in sedentary time. Nevertheless, this controversy should not discourage the development of combined intervention strategies in the future.

As mentioned earlier, many official reports recommend reducing total sedentary time and avoiding extended sitting periods despite the fact that additional studies are needed in order to clarify the associations between sedentary behavior and health risks (Chief Medical Officers, 2011, p. 34; Garber et al., 2011, p. 1334). In order to achieve such reductions, change in behavior is required. For this purpose, insights can be gained from the behavioral epidemiology domain. Sallis, Owen, & Fotheringham (2000, p. 294) define that behavioral epidemiology "has the explicit purpose of understanding and influencing healthful behavior patterns, as part of population-wide initiatives to prevent disease and promote health." Within the behavioral epidemiology domain, a framework was developed to provide a general research sequence for the implementation of evidence-based public health interventions (Sallis et al., 2000, p. 294). The framework consists of five phases. First, associations between behaviors and health are documented including dose-response relationships. Second, methods for measuring the behavior are developed, which serve to inform all stages of research. Third, factors that influence the behavior are researched. This is to inform how the behavior varies by various demographic factors. One purpose of this phase is to identify people who require intervention the most. Fourth, based on the knowledge gained from the previous phases, interventions to change the behavior are developed and evaluated. Finally, interventions that have shown to be effective are put into practice in order to influence health of the overall population. This framework can be applied here as well. While research relating to the first three phases of the behavioral epidemiology framework was presented in the literature review chapter, this particular chapter focuses on the fourth phase by giving an overview of interventions that target sedentary behavior. Furthermore, findings from these interventions are presented. While there is an abundance of interventions on sedentary behavior in a leisure context such as television viewing, this review focuses on interventions in an office environment.

The behavior change wheel is a model that presents sources of behavior and, based on those, establishes a connection to nine types of intervention functions as shown in Figure 2 (Michie, van Stralen, & West, 2011, p. 1). The authors define interventions as "activities aimed at changing behavior" (Michie et al., 2011, p. 6). Furthermore, the framework links intervention functions to policy categories, which are not discussed in more detail.

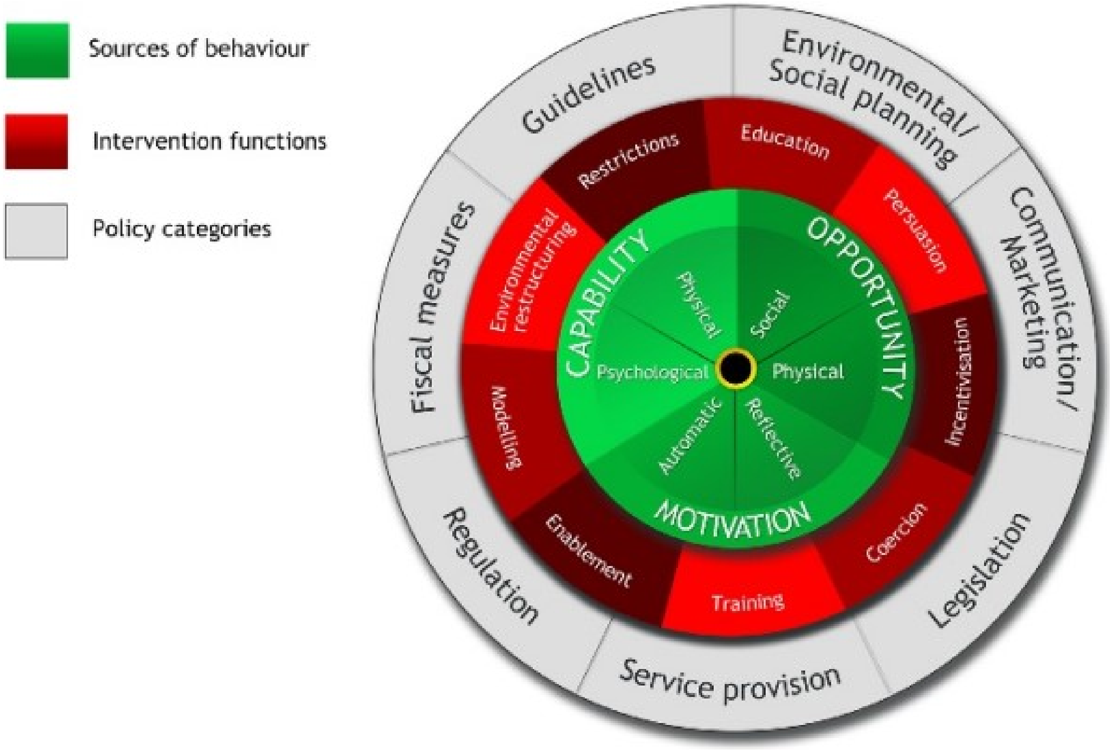

Figure 2: Behavior change wheel (Michie et al., 2011, p. 7)

According to the model, sources of behavior are capability, motivation, and opportunity (Michie et al., 2011, p. 4). They define those terms as follow:

- Capability: "the individual's psychological and physical capacity to engage in the activity concerned. It includes having the necessary knowledge and skills."
- Motivation: "all those brain processes that energize and direct behaviour, not just goals and conscious decision-making. It includes habitual processes, emotional responding, as well as analytical decision-making."
- Opportunity: "all the factors that lie outside the individual that make the behaviour possible or prompt it."

The authors have provided very specific definitions of the intervention functions that oftentimes differ from everyday language (Michie et al., 2011, p. 6). Therefore, the definitions and examples are provided in Table 1.

Interventions	**Definition**	**Examples**
Education	Increasing knowledge or understanding	Providing information to promote healthy eating
Persuasion	Using communication to induce positive or negative feelings or stimulate action	Using imagery to motivate increases in physical activity
Incentivisation	Creating expectation of reward	Using prize draws to induce attempts to stop smoking
Coercion	Creating expectation of punishment or cost	Raising the financial cost to reduce excessive alcohol consumption
Training	Imparting skills	Advanced driver training to increase safe driving
Restriction	Using rules to reduce the opportunity to engage in the target behavior (or to increase the target behavior by reducing the opportunity to engage in competing behaviors)	Prohibiting sales of solvents to people under 18 to reduce use for intoxication
Environmental restructuring	Changing the physical or social context	Providing on-screen prompts for general practitioners to ask about smoking behavior
Modelling	Providing an example for people to aspire or to imitate	Using TV drama scenes involving safe-sex practices to increase condom use
Enablement	Increasing means/reducing barriers to increase capability or opportunity	Behavioral support for smoking cessation, medication for cognitive deficits, surgery to reduce obesity, prostheses to promote physical activity

Table 1: Intervention functions - definitions and examples (Michie et al., 2011, p. 7)

The behavior change wheel provides a way to classify and analyze interventions and intervention functions (Michie et al., 2011, p. 7). Furthermore, it helps to understand the nature of a particular behavior and can guide the choice of appropriate intervention strategies. This is likely to increase the effectiveness of interventions (Michie et al., 2011, p. 2). Additionally, by identifying multiple intervention functions, it prevents important options for intervention from being forgotten (Michie et al., 2011, p. 8). Despite the good overview of intervention functions that the behavior change provides, it can be argued that the link between the sources of behavior and the intervention functions is not always as concise as depicted in Figure 2. For example, environmental restructuring can also affect the opportunity as a source of behavior. Furthermore, education can have an impact on the motivation. However, this does not reduce the usefulness of the behavior change wheel. Therefore, it is used in the context of this research in order to classify and analyze interventions on sedentary behavior. Hereafter an overview of such interventions is presented. However, the overview is limited to the most important interventions in the context of this research and does not claim to be exhaustive.

3.1 Examples of Interventions

Gilson et al. (2009) implemented a walking intervention in order to research associations with sedentary behavior in an office environment. For this purpose, participants were requested to walk more during the workday. The first intervention group was asked to increase "brisk, sustained, route-based walking during work breaks", while the second was directed to increase "incidental walking and accumulate step counts during working tasks". In order to monitor their step counts, participants were provided with a pedometer. Thus, according to the behavior change wheel, this research combines an approach of persuasion (instructions to increase walking and suggestions how to achieve this) and environmental restructuring (use of a pedometer). As a result, both intervention groups significantly increased their step counts in comparison to a control group. However, no significant change in sedentary behavior could be measured. This suggests that walking interventions do not necessarily encourage a significant reduction in sedentary time.

In order to reduce sedentary behavior, many studies have focused on the usage of sit-stand desks and workstations (Alkhajah et al., 2012; Buckley et al., 2015; Gilson, Suppini, Ryde, Brown, & Brown, 2012; Karakolis & Callaghan, 2014; Neuhaus, Healy, Dunstan, Owen, & Eakin, 2014; Straker et al., 2013; Wilks, Mortimer, & Nylén, 2006). While most desks are height-adjustable, a sit-stand desk or workstation is referred to as one that is adjustable between sitting and standing position quickly and conveniently (Straker et al., 2013, p. 519). According to Buckley et al. (2015, p. 3), it is estimated that 90 percent of office workers in Scandinavia have the possibility to work on sit-stand workstations compared to one percent in the UK. One study among 131 Swedish call center workers which objectively measured sitting and standing during one full work shift revealed a 5.3 percent lower total sedentary time of workers at a sit-stand desk (Straker et al., 2013, p. 519). Another study evaluated changes in sedentary time and physical activity levels one week and three months after the introduction of a sit-stand workstation at the workplace (Alkhajah et al., 2012). As a result, sedentary time was reduced by more than two hours per day and mainly replaced by standing, relative to the comparison group. Furthermore, over 90 percent of participants "either agreed or strongly agreed that the workstation was easy to use" (Alkhajah et al., 2012, p. 300). On the other hand, only 33 percent agreed that the workstation had a positive effect on productivity, while 22 percent disagreed. On a larger scale, a review of eight studies concluded that sit-stand workstations do not impact productivity negatively (Karakolis & Callaghan, 2014, p. 799). Among these studies, three reported an increase in productivity, four reported no change, and only one revealed a decrease. Furthermore, it is important to note that the usage of sit-stand desks should not result in prolonged periods of static standing due to their negative impact on health (Messing, Stock, Côté, & Tissot, 2015, p. D11).

According to the behavior change wheel, the usage of sit-stand workstations represents an environmental restructuring intervention. However, it has been argued that changes in the office environment only might not guarantee sustainable change in behavior (Buckley et al., 2015, p. 4). Karakolis & Callaghan (2014, p. 799) point out that studies which demonstrate a substantial amount of standing among workers when provided with a sit-stand workstation evaluate the short-term effects only. On the other hand, long-term studies report a substantial decrease in compliance with the intervention goals (Karakolis & Callaghan, 2014, p. 799). An additional factor influencing the compliance is the provision of usage instructions (Wilks et al., 2006, p. 359). Usage instructions provided by a physiotherapist or ergonomist almost doubled the likeliness to use the sit-stand desk at least once a day. According to the behavior change wheel, the provision of usage instructions represents an education intervention. These findings demonstrate the importance of combining an environmental restructuring intervention with other intervention functions, in this case an educational approach.

The beneficial aspects of combining multiple intervention functions are highlighted by findings from a study that compared the sitting time following the introduction of a height-adjustable workstation to the sitting time following a multi-component intervention (Neuhaus et al., 2014). It was demonstrated that the multi-component intervention reduced the sitting time three times as much as the workstation intervention. The multi-component intervention strategy included interventions on an organizational, environmental, and individual level. Interventions on the organizational level included a consultation with the manager, an information session for the whole staff, and e-mails from the manager to the employees. The consultation with the manager included a discussion how the goals of stand up, sit less, and move more can be achieved in their context. On an environmental level, a height-adjustable workstation was introduced and guidance on its use was provided. Interventions on the individual level "included face-to-face coaching, a tailored e-mail, three telephone calls, an information booklet, and a self-monitoring tool" (Neuhaus et al., 2014, p. 33). It becomes apparent that the employed intervention components target several intervention functions according to the behavior change wheel. However, it must be noted that employing such a variety of intervention components in one intervention complicates determining to which amount the single components contribute to the overall success (Neuhaus et al., 2014, p. 38). The finding that multi-component interventions can reduce sedentary time substantially was proven in another study as well (Healy et al., 2013). However, both studies only captured the medium and short-term outcomes with intervention periods of three months and four weeks. Therefore, more research is required in order to evaluate the long-term outcomes.

Furthermore, prompting software installed on the computer of office workers was studied as an intervention targeting sedentary behavior (Evans et al., 2012). The prompting software was started automatically with the operating system and displayed an advice window for one minute every 30 minutes. It was not possible to minimize or move the window, but work could be continued around the window. The intervention group was equipped with the prompting software and received education on the health risks of prolonged sitting, while the comparison group only received education on the matter. Thus, according to the behavior change wheel, this study combined education, environmental restructuring (using prompting software), and restriction (the prompting software makes it difficult to get computer work done during one minute) as intervention functions. Participants wore a posture monitor in order to measure their sedentary behavior objectively. The study found that there was no difference in the total sedentary time. However, the number and accumulated time of prolonged bouts of sitting (>30 min) were reduced in the intervention group, while there was no change in the comparison group. Despite its short intervention period and the small sample size, this research underlines once again the ineffectiveness of education-only interventions. Furthermore, it demonstrates that computer-based prompts are a possible solution in order to reduce prolonged bouts of sitting in particular.

The approach of using computer-based prompts as an intervention strategy has been researched in conjunction with the sitting pad (Gilson et al., 2016) that was described earlier as a means of measuring sedentary behavior. For this purpose, the sitting pad was combined with a traffic light system on the computer screen of office workers. The sitting pad consists of a cushion containing a pressure sensor and is thus able to detect periods of sitting. In accordance with current recommendations on the duration of sedentary time, the traffic light system was configured to switch from green to amber after 30 minutes and from amber to red after 60 minutes of continuous sitting. The timer was automatically reset if no sitting was detected for five minutes. Besides receiving the sitting pad with the traffic light system, the workers in the intervention group (n=24) attended a one-hour workshop on benefits of decreasing sedentary behavior and increasing physical activity. The workers in the control group (n=33) only attended the workshop. As a result, the total sedentary time reduced from 372 to 359 minutes per day in the intervention group, while it increased from 370 to 380 minutes per day in the control group. Furthermore, the longest bout of sitting decreased from 111 to 96 minutes per day in the intervention group, while it increased from 100 to 117 minutes in the control group. The study does not provide an explanation for the increase of both values in the control group. While the computer-based prompts in the previously described study were passive and thus did not adapt to the individual sitting behavior of the user, the sitting pad combined with the traffic light system has the benefit of being reactive. However, Gilson et al. (2016, p. 4) point out that further research is needed in order to determine the differences in intervention success between passive and reactive prompts. Both interventions that use computer-based prompts targeted specifically computer workers in an office environment as prompts are displayed on a computer screen.

Among the discussed intervention strategies, the sitting pad combined with computer-based prompts is one of the most promising ideas for influencing sedentary behavior. This is because it offers a reliable method for detecting sitting and its prompts are reactive by considering the individual sitting behavior. Furthermore, it does not have issues of compliance once it is placed on the chair, which is often the problem of mobile devices. Despite its positive features, the idea of sitting pad nonetheless offers room for improvement. In the context of this research, it is to be developed further by enabling the sitting pad itself to emit auditory or tactile notifications. This would present several benefits. First, the notifications are not limited to computer workers only as no computer screen is required. Second, the sitting pad acts as a standalone solution without any connection to the computer and thus does not require installation of software on the computer. Furthermore, as a standalone solution the sitting pad is easily transferred between workers and can thus be used for intervention campaigns. More details on these suggested improvements and their justification can be found in the following chapter. This research also encompasses the implementation of the suggested product and its evaluation as part of an intervention targeting sedentary behavior.

4 Design

The aim of this chapter is to provide a design solution as an improvement of the sitting pad described by Ryde et al. (2012) and Gilson et al. (2016). The overall objective of this design solution is to reduce the length of sitting bouts, which is assessed in Chapter 6. This objective is based on research findings that suggest that prolonged bouts of sitting pose health risks.

Therefore, the original sitting pad and its features are described in detail in order to provide a base for further development. Improvement suggestions to the sitting pad are then described and justified. Their implementation and technical feasibility is described in Chapter 5.

4.1 Overview of the Sitting Pad

The sitting pad as described by Ryde et al. (2012) is a prototype device with the dimensions of 43 cm x 32 cm x 2 cm (Figure 3). The seat cushion contains a pressure sensor that is attached to a microcontroller for recording each transition greater than three seconds between sitting and standing or vice versa. Minimum load of the sitting pad is 3 kg.

In a later study (Gilson et al., 2016) the sitting pad was used in connection with a software package in order to provide real time prompts about sitting behavior on a computer screen in the form of a traffic light system. Unfortunately, it was not possible to gain detailed specifications of the sitting pad from the mentioned scientific papers. Therefore, I contacted Gemma Ryde via email in February 2016 in order to find out more about the technical details of the sitting pad. However, she was not able to disclose information as the team was in the process of commercializing the sitting pad. This explains the limited amount of information found in these scientific papers.

Figure 3: The sitting pad on an office chair (Ryde et al., 2012, p. 384)

During the work on this research topic, a commercial product resembling the sitting pad was introduced to the market. Preparations for shipping started in January 2016. The company behind it is Darma Inc, which was founded in California in 2014 and acts under the slogan "Sit Smart". Their products are marketed under the name Darma and come in three versions: Darma Pro, Darma Sit, and Darma Stress. The Darma Pro contains all features, while Darma Sit and Darma Stress only provide limited features. Therefore, only the Darma Pro and its features are described hereafter. It is a sitting cushion with dimensions of 40 cm x 40 cm x 3 cm (Figure 4) and contains 1mm thin fiber optic sensors and memory foam (Kickstarter, n.d.). Its outside is made from artificial leather. Via Bluetooth it connects to the smartphone and transmits information about heart rate, respiratory rate, and posture. Android and iOS apps are available for this purpose. It contains a Li-ion battery that can power the device for one month before it needs recharging. A detailed technical description on its functionality is contained in the patent application, which was filed June 14th 2015 and published March 31st 2016 (Hu, 2016). However, I was not able to identify scientific research regarding these products. Furthermore, due to time constraints, it was not possible to use the Darma products as part of this research.

Figure 4: The Darma sitting cushion (Darma Inc., n.d.)

4.2 Benefits of the Sitting Pad

This sections aims at highlighting the benefits of the sitting pad in order to maintain them while making improvements. The sitting pad is able to record sitting behavior objectively and can track transitions greater than three seconds from sitting to standing or vice versa. This timeframe is suitable as it allows for adjustments of the sitting position without distorting data. Therefore, the tracking time should at least be three seconds; even a five-second interval could be used as it still guarantees sufficient precision given the notification interval. Furthermore, the concept of the sitting pad as a dedicated device considers that sitting time is usually accumulated in one location. Therefore, it does not pose a problem that the sitting pad is an immobile solution compared to mobile apps for example. Instead, it offers the benefit of increased compliance as it cannot be forgotten to use it once it is setup. Furthermore, it is non-obtrusive to the user.

4.3 Improvement Suggestions

The sitting pad is able to track all sitting that takes place on a designated chair. This is independent of the type of work that is performed while being seated. Therefore, displaying notifications on a computer screen might not be suitable for all types of office workers, especially those that perform only some or none of their tasks with the computer. While the number of this type of office workers is likely to be low, it would be preferable to have the sitting pad itself emit notifications.

Furthermore, the computer is a device with many notifications and events that compete for the attention of the user. Therefore, it is assumed that the computer screen is not the most favorable solution for providing notifications on breaking sedentary behavior, as the notifications might not receive much attention. Renfree & Cox (2016) argue similarly that the usage of smartphones to display notifications on sedentary behavior should be avoided due to their multitude of notifications. Instead, the sitting pad itself should emit notifications. This additionally enhances the directness of the system as the notifications originate from the location where an action needs to happen.

The size of the sitting pad needs to be adapted to the office chair it is used on. This is to prevent the sitting pad from shifting during use. Furthermore, a sitting pad covering the entire seat surface can detect all kinds of sitting positions, even unusual ones. In the context of this research, measurements for the sitting pad can originate from the type of office chair that is predominantly found in the University of Tampere.

The sitting pad as presented by Gilson et al. (2016) uses a traffic light system that switches from green to amber after 30 minutes of continuous sitting and from amber to red after 60 minutes. This 30-minute threshold is frequently found in literature (Evans et al., 2012, p. 296; Healy et al., 2013, p. 46; Neuhaus et al., 2014, p. 32). However, I suggest that the sitting pad should emit notifications after 25 minutes. This timeframe originates from the Pomodoro technique, a tool and process aimed at improving productivity (Cirillo, 2006, p. 3). The Pomodoro technique divides work into blocks of time called Pomodoros. Each Pomodoro consists of 25 minutes of work and a 5-minute break. During each work period, the aim is to focus on a specific task without being interrupted by other things. A list of tasks can help keeping track of the workload and offers the possibility to analyze how many Pomodoros a certain task required. The 5-minute break is aimed at disconnecting from the task and it is suggested to engage in healthy behavior such as standing up, walking in the room, and drinking some water (Cirillo, 2006, p. 7). The Pomodoro technique has received much attention in literature as a productivity technique for various contexts (Abrahamsson et al., 2008, p. 180ff.; Conlon, 2016, p. 157ff.; Hines, 2010, p. 45).

This technique is applied because its aims are very similar to the objectives of the sitting pad. However, the Pomodoro technique suggests using a kitchen clock in order to keep track of time, which always requires manual setting. This manual effort could result in decreased usage or even discontinuation of usage. The sitting pad can automate the setting of the timer while maintaining the same functionality. Furthermore, it is believed that the 25-minute work and 5-minute break cycle adapts better to business life. In business life, meetings are oftentimes scheduled in half hour cycles. Thus, a 25-minute work interval could offer a 5-minute break before attending the next meeting.

As the sitting pad is designed for office use, the user of the sitting pad is likely surrounded by other workers. Thus, it must be assured that notifications are provided in a non-obtrusive manner. This is possible using auditory or tactile notifications. When using auditory notifications, their volume would have to be subtle in order to avoid disturbance of others, but loud enough to be perceived by the user. However, it must be noted that hearing abilities vary largely, both between people of the same age and different ages. Furthermore, the number of deaf or hearing-impaired people must not be underestimated. An additional factor that influences the perception of auditory notifications is the background noise. In loud environments, such notifications might not be heard. Additionally, the type of auditory notification should be considered. A single tone is likely to be less obtrusive than a melody. On the other hand, it is more likely to be missed. The same consideration applies to the duration of auditory notification. A longer notification is less likely to be missed, while a shorter one is less obtrusive. Therefore, the use of tactile notification is preferred. Only the user can perceive them and the number of people with skin perception impairments is smaller than the ones with hearing impairments. Furthermore, in most office environments the clothing of the user should not hinder the transmission of tactile notifications. However, tactile notifications might result in noise due to resonance bodies such as the office chair itself, which could disturb others. Additionally, it must be assured that the tactile notifications are pleasant for the user. Thus, their intensity must be suitable and originate from a location inside the sitting pad that does not cause discomfort. Close to the backrest of the chair represents an appropriate location in order to avoid contact with erogenous zones of the thighs. Vibrations in those zones might cause inappropriate and unpleasant sensations. However, it is likely that preferences vary between people.

Furthermore, the sitting pad is to be used as a standalone solution. Thus, all technology required for the functionality of the sitting pad is supposed to be fitted to the office chair. This offers the benefit of not having any cables leading to and from the chair, which reduces the risk of injuries to the user. Furthermore, a standalone solution offers the benefit of being able to transfer the sitting pad to another user easily. Such a scenario is imaginable during workplace interventions on sedentary behavior when the target is to make workers aware of their sitting patterns during a limited period of time.

4.4 Technical Specification of the Design

Based on the improvement suggestions justified above, the ideal sitting pad has the following characteristics. Its size is 47 cm x 35 cm and it is made of soft material covered by a fabric exterior. It is as thin as possible. The tactile notification is emitted by the sitting pad close to the backrest of the office chair for a duration of two seconds. A suitable intensity must be determined through prototyping. The notification is emitted after 25 minutes of continuous sitting. The sitting pad can distinguish between the user sitting and not sitting with an interval of five seconds. For the purpose of this research, this data needs to be stored permanently and be easily transferrable to a computer for analysis. Furthermore, this research requires a possibility to turn notifications off while maintaining the ability to record sitting data.

5 Implementation

When starting the implementation, it would have been of benefit to draw from existing experience regarding development of such a device. As mentioned previously, I contacted Gemma Ryde via email in order to find out more about the technical details of the sitting pad. However, she was not able to disclose information as the team was in the process of commercializing the sitting pad. Furthermore, when starting the implementation, the patent of the Darma sitting cushion that could have provided clues to facilitate implementation was not yet published.

5.1 Technical Platform

Based on the design solution presented in the previous chapter, I decided to use the Arduino as a technical platform. It is an open-source platform for constructing electronic devices and a variety of Arduino circuit boards are available that can be individually programmed to perform a number of tasks (Badamasi, 2014). These Arduino microcontrollers can read information from input devices such as sensors and send information to output devices such as loudspeakers (Badamasi, 2014) . The various Arduino circuit boards offer different functionality. For the purpose of this implementation, the Arduino Uno is employed, a widely used and thus well-documented microcontroller. At a price of around 20 euros, it is inexpensive and its operating voltage is 5V. Therefore, it can be powered using a USB battery pack. The energy consumption depends on the use-case, however it is estimated that using it for the purposes of the sitting pad does not require much energy. Thus, it is probable to reach a satisfactory battery life.

However, the Arduino Uno does not provide the functionality of storing data permanently. Each power cut resets the device and thus all stored data is deleted. Furthermore, it does only offer a small data storage capacity of 32 KB. Another shortcoming of the Arduino Uno is that it does not include a Real-Time-Clock. This means that it can track time intervals only from the moment it is powered on. Thus, dates and times cannot be provided. In order to add both a permanent data storage solution and a Real-Time-Clock to the Arduino Uno, a separate shield was added to it. A shield is a circuit board that can be easily added to the Arduino and extends its capabilities. For this purpose, the Adafruit SD and RTC shield was chosen. It can save data to a SD memory card and is thus immune to power cuts.

5.2 Sensor

The sensor delivers the data on which the notification and thus the functionality of the sitting pad is based. Furthermore, the evaluation part of this research relies on data from the sensor. Therefore, the sensor needs to fulfill high standards in terms of reliability and validity.

The sitting pad developed and introduced by Ryde et al. used a “medical grade pressure sensor […] which acts as a switch to detect transitions of greater than 3 seconds to and from the seat” (Ryde et al., 2012). However, the paper and other publications by the same authors do not provide any further details on the technical implementation. The only information gained was that the pressure sensor is subject to wear. Their solution to this particular problem was to track the time of usage and to replace the sensor when necessary. Consequently, I had to develop my own solution for the sensor technology.

Requirements for the sensor were that it needed to cover the entire surface of the sitting pad in order to guarantee that all types of sitting positions could be detected, e.g. at the very front of the chair with an upright back or very relaxed almost lying on the chair. Another requirement was that any transition between sitting and standing and vice versa needed to be detected in real-time, at least within five seconds.

The first design approach of the sensor was to use the principle of a switch. Thus, the idea was to integrate two layers of conductive material into the sitting pad and to add some material between them that would push them apart when no person was sitting on the pad. The mass of a sitting person would connect the two layers of conductive material and thus close the electrical circuit. The Arduino would be programmed to react to these changes in electrical current. This approach was realized using aluminum foil as conductive material. The two sheets of aluminum foil were both taped to 1 cm thick sheets of polyethylene foam. Those conductive layers were combined facing each other with stripes of the same foam between them in order to separate them when no person was sitting on the pad. Cables were attached to the layers of aluminum foil and connected to the Arduino. The entire product was contained in a fabric pillowcase and closed using safety pins. This gave the sitting pad a soft exterior. First tests with this type of sitting pad were successful. However, as the sitting duration was prolonged, the expansion of the foam between the layers of aluminum foil took more time than the specified five seconds. Thus, the sitting pad detected sitting even though no sitting was taking place. Due to this malfunction, I attempted to modify the stripes of foam between the layers of aluminum foil. More stripes were added and their thickness was increased. However, this could not solve the problems mentioned previously. Another idea based on the same principle of functionality was to use harder materials as a base for the layers of conductive material. Metal springs would be used to separate the layers. However, it soon became obvious that the product would not be comfortable to sit on. Furthermore, this approach would have increased the thickness of the sitting pad substantially. Therefore, it was decided to abandon this approach.

The second approach was to use a force sensor inside the sitting pad to detect sitting. However, it was found that commercially available, low-cost force sensors only covered small areas of several centimeters. It was not possible to identify an affordable force sensor that covered the approximate area of the sitting pad. The alternative of embedding several of the small-area force sensors into the sitting pad was abandoned due to the large number of force sensors this would have required.

The third approach in sensor design was to use air pressure to detect changes in sitting. For this purpose, an air-filled tube would be integrated into the sitting pad and an air-pressure sensor would detect pressure changes in the tube. These changes could be translated to periods of sitting and no sitting. When planning the implementation of this type of sensor, it became obvious that it would be difficult to seal the air-pressure system appropriately and to maintain constant pressure inside it. Therefore, this approach was abandoned before it reached the implementation phase.

The fourth approach in sensor design was to use a capacitive sensor. Capacitive sensing is based on the fact that each object has its own capacitance, which is its ability to hold a charge (Šekoranja, Bašić, Švaco, Šuligoj, & Jerbić, 2014, p. 465). When a person approaches or touches that object, its capacitance changes. These changes in capacitance are measured.

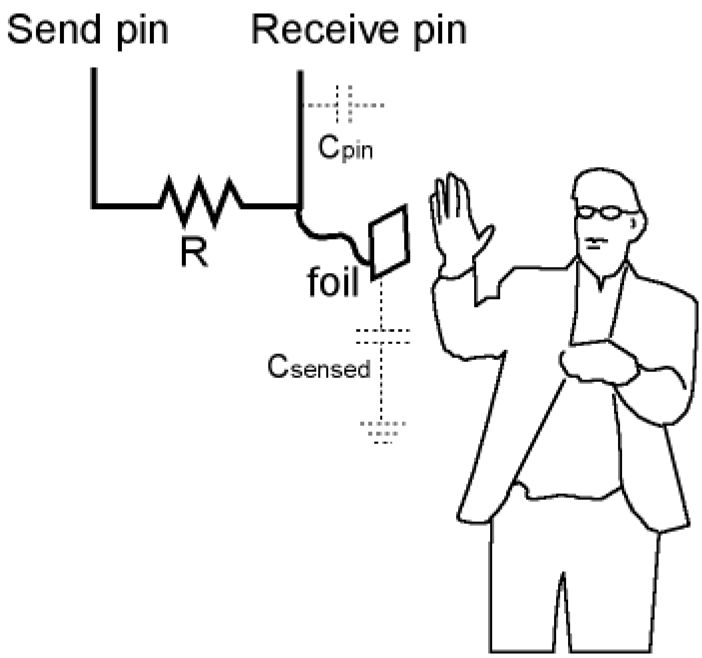

Figure 5: Functionality of capacitive sensing using an Arduino (Badger, n.d.)

For the Arduino, a software library exists for capacitive sensing (Badger, n.d.). It uses one send and one receive pin of the Arduino. Through the send pin a state change is triggered. This state change can be measured on the receive pin with a certain delay. This delay depends on the resistor that is part of the circuit and on any other capacitance such as the human body. The capacitive sensing method finally returns a value that represents the delay in arbitrary units (Badger, n.d.). Based on this value, statements about human proximity are possible.

As depicted in Figure 5, the conductive sensing method requires foil to detect human proximity. However, also any other type of conductive material may be used. I used aluminum foil taped to a layer of 1 cm thick polyethylene foam and covered by the same type of foam. This product was wrapped using a fabric pillowcase. The aluminum foil was connected to the circuit using cables. The resistor used in the circuit influences the sensitivity of the capacitive sensing method. Thus, the resistor has an influence on the distance from which a person is detected. Different resistors were tested in the circuit and a 20 kΩ resistor was found to provide suitable sensitivity levels detecting a person from an approximate 2 cm distance above the sitting pad. The values ranged between 0 (no sitting) and 60 (sitting). It was assumed that a person is usually not present within a 2 cm distance above the sitting pad unless sitting or kneeling on it. However, when testing this product it became obvious that the aluminum foil was not durable enough for use in the sitting pad due to the forces exerted by movements of the user. Furthermore, hard objects in clothing, such as buttons, could damage the aluminum foil. Therefore, a fine metal mesh was used instead. Furthermore, it was found that the cable between the metal mesh and the Arduino had to be shortened and the Arduino had to be placed close (~20 cm) to the sitting pad as human proximity to a long cable showed the same values as a person sitting on the sitting pad. The Arduino was thus contained in a plastic box and fixed under the seat surface using straps. As mentioned previously, it was a requirement to detect transitions between sitting and standing and vice versa in real-time, at least within five seconds. The Arduino was thus programmed to poll the sitting value provided by the sensor every five seconds.

When testing the product using a USB battery pack (9100 mAh) as a power supply, it was found that the battery pack was able to supply energy for several days without recharging. However, it was noticed that the recorded values for sitting (between 0 and 60) became increasingly inaccurate the longer the sitting pad was powered on. Research into the matter found that this behavior could be avoided using a grounded power source. As the battery pack was not able to provide grounding, the USB port of a laptop was used as power supply. However, the laptop had to be connected to the power grid at all times in order to provide reliable grounding. This meant that a cable had to lead from the chair to the laptop and thus entirely free movement with the chair was no longer possible. However, in order to avoid the risk of injuries to the user, a USB extension cord was used that would become detached under pull. While the usage of the sitting pad as a standalone solution was thus restricted, it was not entirely abandoned. The functionality of the sitting pad was still provided by its components only and any laptop or computer could be used to power it, as no additional installation of software was required. Despite the drawbacks, it was decided to use this solution due to time constraints.

5.3 Notification

The sitting pad was designed to emit a notification after 25 minutes of continuous sitting. Reasons for choosing this particular timeframe are provided in Chapter 4. In order to detect 25 minutes of continuous sitting, the Arduino increments a variable whenever the 5-second prompt of the sensor delivers a sitting value. After 300 readings of a sitting value (300 x 5 s = 25 min), the notification is triggered. In case the prompt of the sensor delivers a no sitting value, the variable is reset and thus the timer restarted. However, it was noticed that adjustments of the sitting position during the instant when the sensor was prompted could produce single readings that indicated no sitting. This could lead to the timer being reset unintentionally. Therefore, the Arduino was programmed to allow single readings of no sitting between continuous readings of sitting without resetting the timer. After a notification is played, the timer is reset. Thus, the user will receive a notification after another 25 minutes of continuous sitting. This means that the user gets a notification every 25 minutes if the sitting is not interrupted.

In Chapter 4 it was argued that the most suitable type of notification is tactile feedback. For this reason two cylindrical vibration motors with a diameter of 9 mm and a length of 25 mm (Precision Microdrives 307-100) were integrated into the sitting pad. They were placed at the back of the sitting pad, close to the backrest. The vibration motors were connected to the Arduino and powered using 3.3 V resulting in a vibration frequency of 250 Hz according to the product data sheet. The duration of the tactile notification was set to two seconds in order to be sufficiently long to be noticed while avoiding disturbance due to excessive duration. These vibration parameters were tested with participants and were found to be pleasant. However, it was found that depending on the sitting position of the participants, the sitting pad acted as a resonance body, which resulted in noise. Participants considered this noise tolerable.

After the separate evaluation of the vibration parameters, the tactile notification was evaluated in the context of the anticipated use-case of the sitting pad, i.e. together with the capacitive sensor that provided data about sitting time. This led to the insight that the sensor values did no longer reflect the sitting behavior. When analyzing this anomaly, it was found that the vibration motors interfered with the capacitive sensor resulting in distorted data. In order to solve this problem, I attempted to shield and ground the cables between the Arduino and the vibration motors. However, this did not lead to success. Furthermore, I considered to place the vibration motors elsewhere on the office chair, away from the sitting pad and its capacitive sensor. However, this approach could not guarantee that the vibration could be perceived reliably as the source of the vibration was too far away from the user. Due to time constraints, the decision was reached to abandon the approach of using tactile feedback and to use auditory feedback instead, which had been considered previously. An overview of the benefits and drawbacks of auditory feedback is provided in Chapter 4. For this purpose, the

Arduino was equipped with a piezo element as a buzzer. It was programmed to play a short melody (4.8 seconds). The volume of the melody was 55 dB at the ears of the user when seated on the office chair. This is ca. 20 dB above the general noise level in an office and thus well-perceivable by people without hearing impairments.

5.4 Final Implementation

While the previous sections described the development process and the considerations that played a role, this section describes the final implementation of the sitting pad. The sitting pad consists of a sensor unit and a microcontroller unit that are set up on an office chair (Figures 6 and 7). The sensor unit is made of two layers of polyethylene foam with a metal mesh in-between and a fabric pillowcase on the outside. It is placed on the seat surface of the office chair. The armrests and the backrest restrict the sensor unit from shifting. The Arduino microcontroller unit is contained in a plastic case, which is fixed under the seat surface using straps. One cable connects the sensor unit with the microcontroller unit. Another cable (USB) connects the microcontroller unit with a laptop for power supply. The laptop is placed on a table next to the chair. In order to avoid the risk of injuries to the participant due to the cable between the microcontroller unit and the laptop, a USB extension cord is used that becomes detached under pull. All electrical components connected to the Arduino are soldered to the circuit board in order to guarantee durability. After 25 minutes of continuous sitting, a short melody (4.8 s) is played with a volume of 55 dB at the ears of the user. Short adjustments (<5 s) of the sitting position are possible without interfering with the 25-minute time intervals.

For the evaluation of the sitting pad, it is necessary to collect and permanently store data about sedentary behavior, both with and without playing the auditory notifications. For this purpose, the Arduino microcontroller is equipped with the possibility to store textual data (CSV format) on an SD memory card. The SD card can be removed and read on a computer. The collected data consists of the unixtime (seconds since January 1st 1970), a timestamp (year, month, day, hour, minute, second) and the sensor value (a value between 0 and 60). The values 58, 59, and 60 represent sitting, while the values 0, 1 and 2 are associated with no sitting. The auditory notification can be turned off by modifying the software code on the Arduino.

Figure 6: Front view of the sitting pad setup on an office chair

Figure 7: Side view of the sitting pad with the Arduino contained in a white plastic box

6 Evaluation

In Section 4.3, means of modifying and developing the sitting pad (Ryde et al., 2012; Gilson et al., 2016) were suggested. Furthermore, these modifications were implemented resulting in the sitting pad as described in Section 5.4. As a next step, the aim was to evaluate the influence of the notifications of the sitting pad on sedentary behavior, i.e. the duration of sitting bouts. Therefore, it was necessary to compare the sedentary behavior of participants with and without the notifications.

In order to measure sedentary behavior, a variety of approaches can be used as described in Section 2.5. Automatic data collection was chosen as a suitable method to gain data on sedentary behavior free from bias. Furthermore, no effort from the study participant is required in contrast to self-report measures. While there are a number of means to collect data automatically, it was decided to use the sitting pad for this purpose. Thus, already when modifying and developing the sitting pad, the automatic data collection functionality was considered in order to evaluate the impact of notifications on sedentary behavior. From the automatically collected data it was possible to analyze the duration of sitting bouts, i.e. periods of uninterrupted sitting. Furthermore, the collected data would have offered the possibility to analyze breaks and their duration. However, the informative value would have been low as the reasons for taking breaks from sitting on the office chair vary. Apart from automatic data collection to monitor sedentary behavior, feedback regarding the sitting pad was gathered through interviews. Interviews were chosen as a suitable method due to the small number of study participants. They offer the benefit of flexibility and interesting ideas can be followed and discussed in more detail (Lazar, Feng, & Hochheiser, 2010, p. 179). Despite the challenges to manage the discussion, it is easier to describe detailed perceptions regarding the sitting pad in interviews than in open-ended questions in questionnaires. It must be noted that results from both automatic data collection and the interviews are not generalizable as they originate from two participants only. A larger number of participants would be required to generate generalizable and representative data.

This chapter describes how the two pilot studies were carried out. The first one was carried out in order to determine the validity and reliability of the sitting pad. The second served as a trial run in order to determine the suitability of research methods for the major study. Furthermore, this chapter describes details of the major study in regards to the participants, the procedures, the data treatment methods, and finally the results. These results are discussed in Chapter 7.

6.1 Pilot Studies

The aim of a pilot study is to "try out the research techniques and methods […], see how well they work in practice, and, if necessary, modify […] plans accordingly"

(Blaxter, Hughes, & Tight, 2010, p. 138). As implied in this definition of a pilot study, it can be used in two different ways: As a “small scale version, or trial run, done in preparation for the major study” (Polit, Beck, & Hungler, 2001, p. 467) as well as the “pre-testing or trying out of a particular research instrument” (Van Teijlingen & Hundley, 2010). In the current research, the pilot studies serve both purposes.

Two pilot studies were conducted. The purpose of the first pilot study was to test the validity and reliability of the sitting pad. This approach of testing the validity and reliability of a device before employing it for further purposes was used likewise for the original sitting pad (Ryde et al., 2012; Gilson et al., 2016). The second pilot study aimed at evaluating the feasibility of research techniques and methods before employing them for data collection. Thus, the test scenario of the second pilot study was identical to the anticipated setup of the major study. For both pilot studies, informed consent forms were created that can be found in Appendices 1 and 3. They contain detailed information about the proceedings.

6.1.1 Participants

Based on the anticipated participants of the major study, an office worker at the university was recruited to participate in both pilot studies. The participant was male, weighed between 60 and 70 kg and was between 170 and 180 cm tall. The same participant was not included in the major study in order to avoid contamination of results (Van Teijlingen & Hundley, 2010). The participant used a chair of the ISKU brand that is most commonly found throughout this section of the university. The same type of chair was used for the major study.

6.1.2 First Pilot Study: Validity and Reliability of the Sitting Pad

The first pilot study aimed at evaluating the validity and reliability of the sitting pad. In quantitative research, validity usually refers to “whether the research truly measures that which it was intended to measure or how truthful the research results are” (Joppe, 2000, p. 1). In the context of this research, it meant that the data provided by the sitting pad about the sedentary state corresponds to the actual sedentary state. Furthermore, it meant that, for instance, a person standing next to the chair does not produce any data in the sitting pad that can be interpreted as sitting. Reliability, on the other hand, refers to “the extent to which results are consistent over time and an accurate representation of the total population under study […] and if the results of a study can be reproduced under a similar methodology” (Joppe, 2000, p. 1). In the context of this research, it meant that the data provided by the sitting pad about the sedentary state had to be consistent. Thus, a sitting participant always had to produce the same data, even after standing up and sitting down again. Furthermore, it meant that the data had to be consistent between different participants.

In order to conduct this pilot study, the sitting pad, consisting of the sensor unit and its microcontroller unit, were set up on the office chair. The setup was identical to the one described in Section 5.4. However, in this particular pilot study the connection to the laptop served both as power source and as means of transmitting data. Every five seconds the program on the microcontroller unit queried the sensor unit and produced a numeric value that represented the sedentary state. Together with a timestamp, this value was sent to the connected laptop and displayed in a separate window. Next to this window, a camera image from the built-in webcam was displayed. A self-developed program took a screenshot of the whole screen whenever data was sent to the laptop (Figure 8). From the screenshot, it was thus possible to compare the value recorded by the sitting pad to the real-life sedentary state. As a result, the readings could match each other or not. From this data, the validity was calculated as a percentage value. For those instances when the readings would not match each other, a more detailed analysis would be attempted based on the camera image and the time stamp in order to find reasons for the anomaly. The duration of the pilot study was one working day.

Due to the varying physique between humans, it had to be verified that the data produced by the sitting pad was consistent across participants. Therefore, two additional participants were recruited and asked to perform sitting, standing, and transition tasks. The procedure of recording the participants while performing those tasks was identical to the procedure described above with a screenshot taken every five seconds. Both participants signed an informed consent form that can be found in Appendix 2. One participant was female, weighed between 50 and 60 kg, and was between 170 and 180 cm tall. The second participant was male, weighed between 100 and 110 kg, and was between 190 and 200 cm tall. Both participants were asked to sit down, remain seated for about 30 seconds, then stand up and remain standing for the same duration. This procedure was repeated three times and participants were asked to sit on the chair in a different posture each time. However, the postures were not specified; instead participants could decide themselves in order to test a variety of postures.

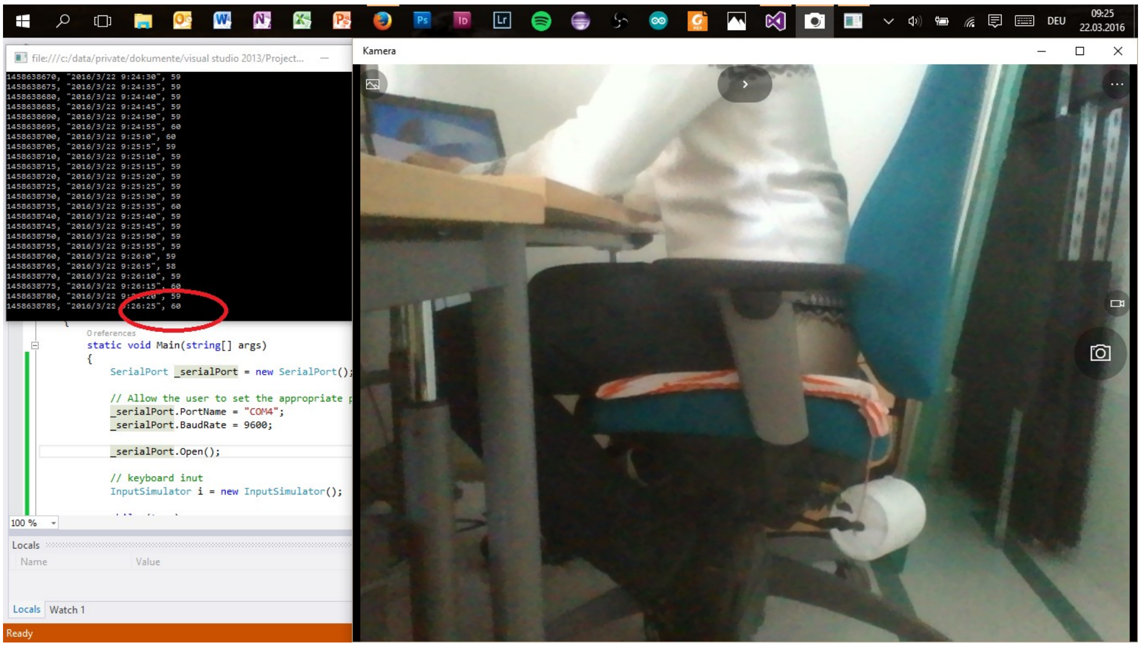

Figure 8: Example of a screenshot used for the pilot study with the webcam image on the right and the data from the sitting pad on the left.

As the result, it was found that the validity of the sitting pad is 100 percent accurate based on 5249 consecutive screenshots analyzed. This means that the value recorded by the sitting pad and the real-life sedentary state always matched each other. The analysis was based on the values 58, 59, and 60 representing sitting, while values of 0, 1 and 2 were associated with no sitting. Even when the participant was seated on the sitting pad only partly, for example at the very front of the seat surface, accurate results with values of 58, 59, and 60 were produced. Standing next to the chair resulted in an accurate value of 0. Figures 9 to 14 provide examples for values from common sitting positions. Based on 89 screenshots that were collected with the additional two participants, it was confirmed that the validity of the sitting pad is 100 percent accurate. Thus, it can be concluded that the developed sitting pad is a valid and reliable tool for measuring sedentary behavior.

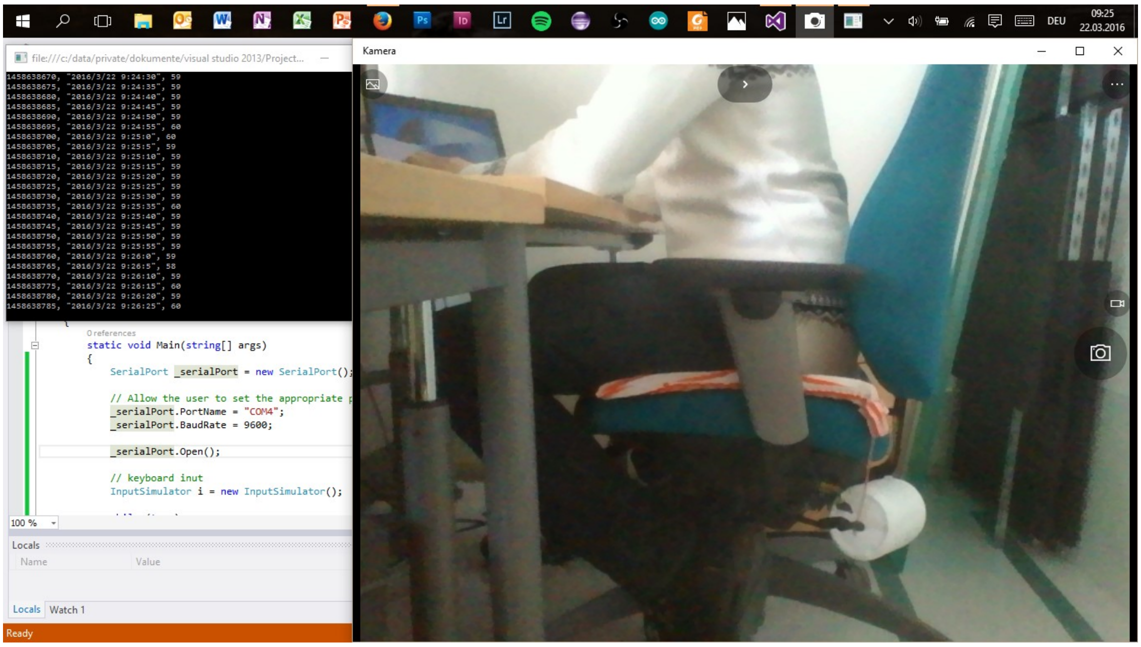

Figure 9: Standard sitting posture (value: 60)

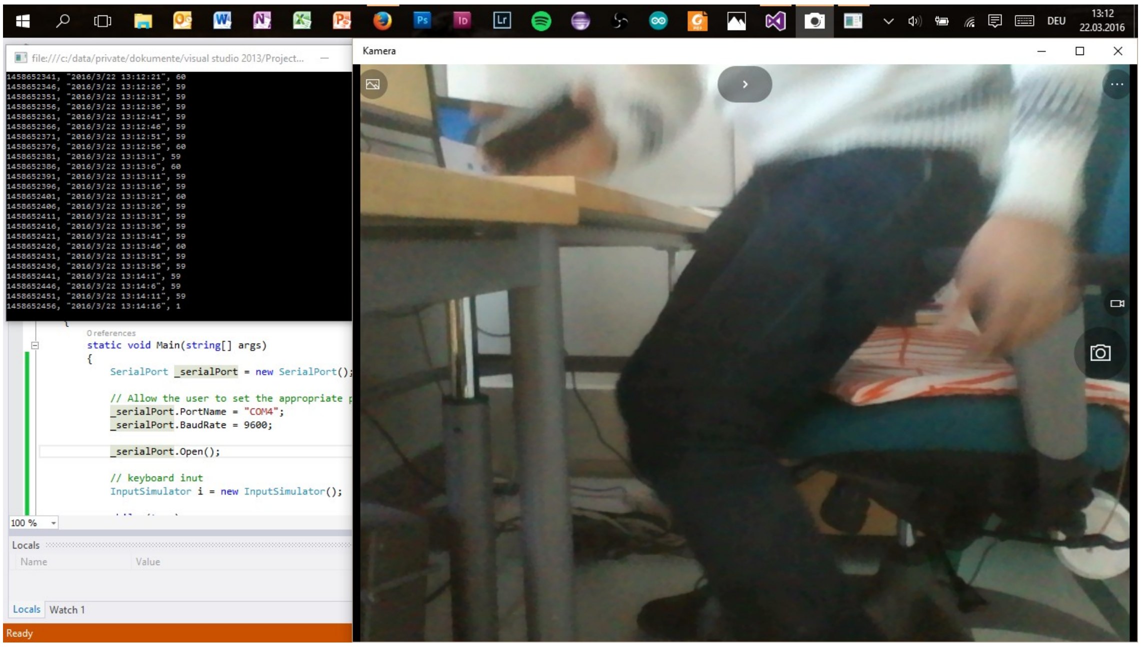

Figure 10: Transition from sitting to standing (value: 1)

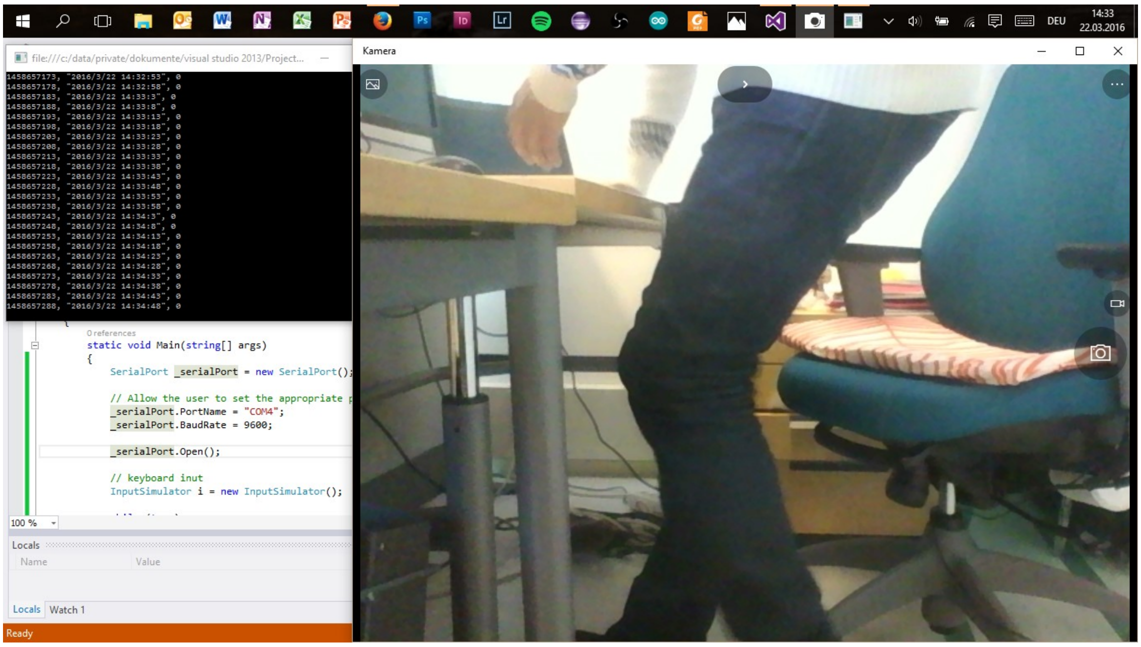

Figure 11: Transition from standing to sitting (value: 0)

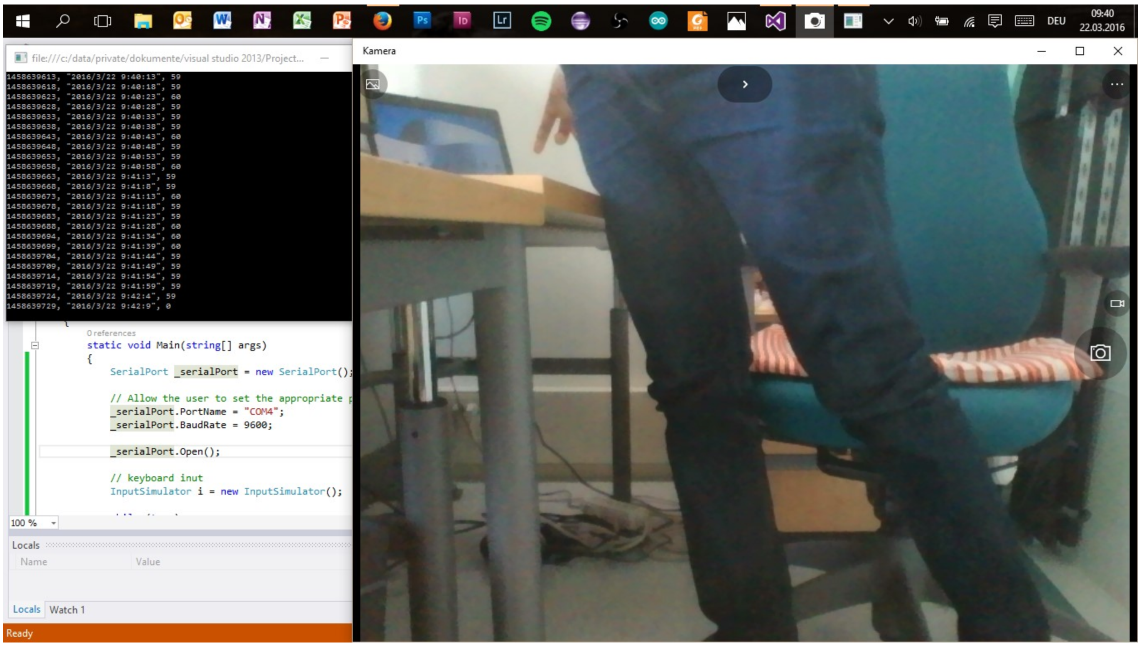

Figure 12: Standing (value: 0)

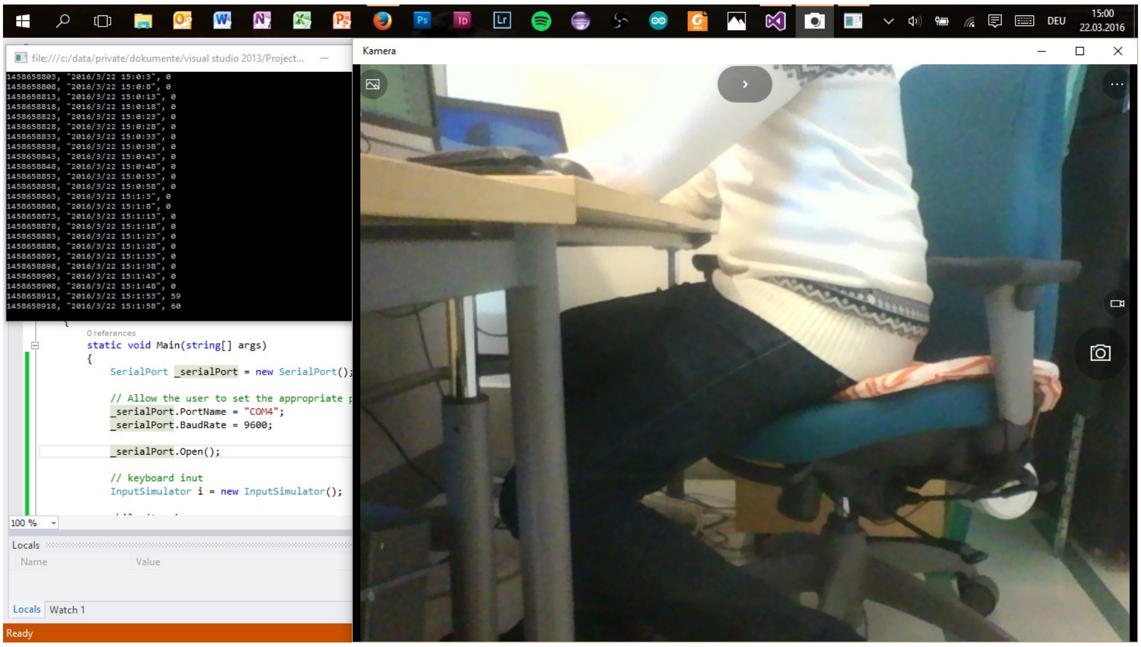

Figure 13: Sitting on parts of the sitting pad only (value: 60)

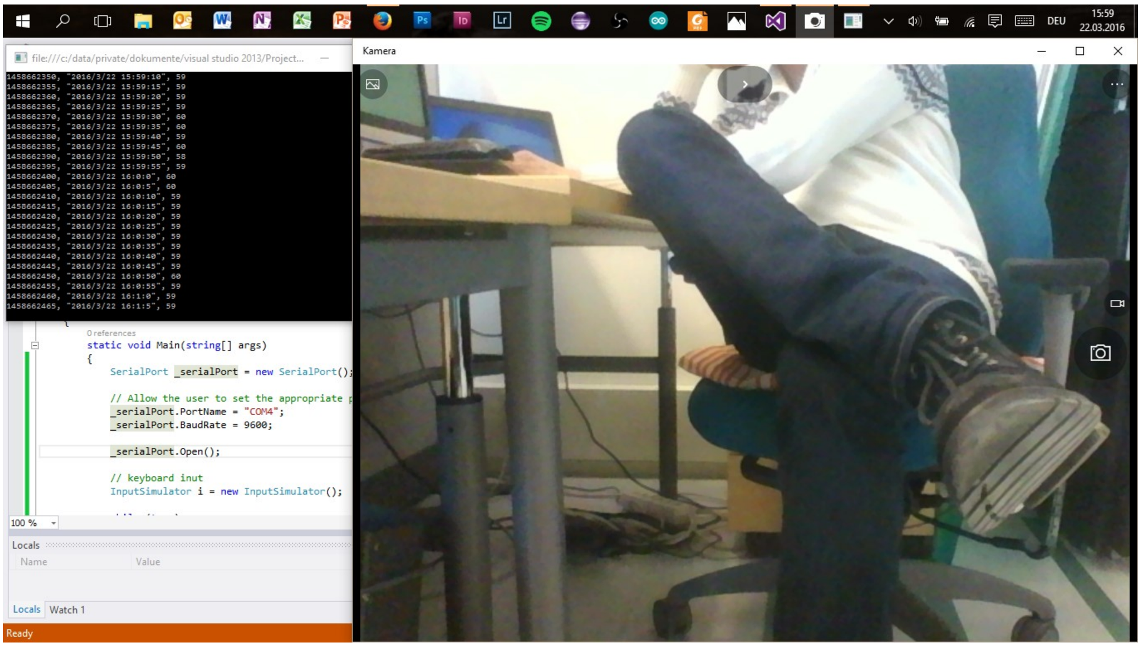

Figure 14: Sitting in a relaxed position (value: 59)

6.1.3 Second Pilot Study: Evaluating the Feasibility of Research Techniques and Methods

The second pilot study aimed at evaluating the feasibility of research techniques and methods to be used in the major study and was conducted using the same participant as in the first pilot study. While the first pilot study already demonstrated the validity and reliability of the data collected by the sitting pad, this particular pilot study served as a "small scale version, or trial run, done in preparation for the major study" (Polit et al., 2001, p. 467). In particular, this meant to verify that apart from collecting data in a valid and reliable way, the sitting pad notified the participant reliably and that the sitting data was recorded to the SD card. Furthermore, the second pilot study served to assure that all components would work together smoothly. For this purpose, it was carried out in the identical surroundings as anticipated for the major study, i.e. at the university in an office environment.

In order to conduct this pilot study, the sitting pad, consisting of the sensor unit and its microcontroller unit, were set up on the office chair as described in Section 5.4. In contrast to the first pilot study, no further modifications to the setup were made. The duration of the pilot study was one working day. After the pilot study at the end of the day, a short interview with the participant was held. In the interview it was asked whether the usage of the sitting pad was safe, pleasant, and useful. Furthermore, it was inquired whether the auditory notification was pleasant and its volume appropriate. Additionally, it was studied whether the participant could imagine using the sitting pad for an extended timeframe. The complete set of questions can be found in Appendix 4. The recorded data on the SD card was analyzed using the data analysis methods intended for the major study to assure their feasibility. Finally, the data was discarded as it was not needed any longer.

The interview led to a number of results. According to the participant, no comfort difference was perceived between sitting on an office chair with and without the sitting pad. Thus, it was not considered to be disturbing. Based on the appearance and the setup of the sitting pad, the participant considered it safe. In terms of usefulness, the participant noted that the idea of reminding the user about prolonged sitting is useful. However, the participant could not recall having received any notifications on prolonged sitting during the workday despite long periods of sitting. This led to a more detailed inquisition on the matter and it was found that the USB extension cord that powered the sitting pad was faulty and was thus replaced. Therefore, it was also not possible to gain feedback on the pleasantness and the volume of the auditory notification. The participant could imagine using the sitting pad both for two weeks and for a longer period of time as it did not interfere with the work and could provide useful information when working correctly. Due to the detected fault, no data was stored on the SD card. Therefore, the second pilot study was repeated with the same user. The data analysis methods on the recorded data were successful. In order to avoid further disturbance of the participant, another interview was omitted. Only feedback on the auditory notification was collected as it was not possible to gain it previously. The participant stated that the notification was not disturbing and that the volume was suitable for a quiet office environment.

6.2 Major Study

6.2.1 Participants

In order to facilitate the recruiting process, office workers at the university were targeted as participants in this research. For this reason, the pilot studies already used such participants. Furthermore, it was assumed that the office environment at the university and at a company are not considerably different. Thus, it is likely that the findings are transferrable. The scope of this research did not allow for a representative evaluation of the ability of the sitting pad to modify sedentary behavior. The focus was instead on collecting feedback on the sitting pad and hints on its ability to modify sedentary behavior. For this purpose, the aim was to recruit two participants.

Behavior change can only occur when the person believes that change is necessary. Therefore, it had to be assured that the recruited study participants perceived a need in changing their patterns of sedentary behavior. For this purpose, potential participants of this study were asked to fill out a questionnaire on their attitudes regarding sitting and the need to change it. Specifically, the questionnaire asked whether they take too few breaks, whether they sit too much during the work day, and whether prolonged sitting has negative health effects. Furthermore, two questions were included to assure that they do not have the possibility to work in a standing position because the study targeted seated office workers specifically. Additionally, two questions asked about their estimated sitting time in their office at their desk and sitting time elsewhere during work hours, such as meetings and seminars. These were included to guarantee that a substantial amount of sitting would be trackable by the sitting pad. The complete set of questions can be found in Appendix 6. The questionnaire was handed to two potential participants. As their answers were satisfactory for participation in the study, they were selected. Furthermore, it was assured that they had not planned to spend more than one day per week away from the office during the participation period. Both participants signed an informed consent form that can be found in Appendix 5.

The first participant (P1) was female, weighed between 60 and 70 kg, and was between 160 and 170 cm tall. The second participant (P2) was male, weighed between 100 and 110 kg, and was between 190 and 200 cm tall. None of the participants had participated in the pilot studies. The participants did not receive any reward for participating in this study.

6.2.2 Procedures

In order to conduct the study, the sitting pad was setup on an office chair as described in Section 5.4. Each participant was asked to use the sitting pad for two calendar weeks. During the first week, the sitting pad was solely used to collect data about the sitting behavior of the participant. For this purpose, the auditory notification of the sitting pad was turned off. During the second week, the sitting pad reminded the participants to take breaks after 25 minutes of continuous sitting using an auditory notification, while collecting data about the sitting behavior. The sitting pad was always set up on a Friday afternoon just before the participants finished their workweek in order to assure complete data collection from Monday morning onwards. After these two weeks of automated data collection, the participants were interviewed in order to gain a deeper understanding of their perceptions of the sitting pad. The questions to guide the interview can be found in Appendix 7. Due to unforeseen personal events, P1 only spent limited amount of time at the office during the second week of participation in the study. Therefore, data collection was prolonged for another calendar week and the data of the week with limited amount of office time was discarded.

6.2.3 Data Treatment

The data collected by the sitting pad was treated in several steps. First, it was downloaded onto a computer from the SD memory card in the CSV file format. This data was opened in Microsoft Excel. The possibility of power disruptions of the sitting pad, which was due to the previously described safety mechanism in the cable between the microcontroller and the laptop, could result in data being distributed over several files. These files were then merged. As a second step, the weekend data was removed in order to shrink the dataset, because no sitting took place at the office during weekends. Third, the data was distributed into spreadsheet columns for easier analysis as the sitting pad collected them as comma-separated values only. As a fourth step, the amount of missing data resulting from power cuts of the sitting pad was analyzed. Fifth, the sitting values collected from the sensor of the sitting pad were examined. In this research, sitting was considered a binary phenomenon (sitting / no sitting). However, as the sensor of the sitting pad recognizes proximity, it is able to provide a value range from 0 to 60. As already established in the pilot study, the values 0, 1, and 2 represent no sitting. On the other hand, the values 58, 59, and 60 represent sitting. In the pilot study, only these values were recorded. However, in the major study it was found that there were rare instances of the values in-between. An analysis of these values concluded that some originated from transitions between sitting and standing and vice versa. Furthermore, there were short (one or two-minute) and rare periods with an accumulation of the in-between values. Based on the data before and after these periods, they occurred only during times when the user was not sitting on the chair. Moreover, in many cases the time of occurrence (night) implied that the user was not using the chair. In conclusion, they do not influence the overall validity of the sitting pad. It is likely that these phenomena were not observed during the pilot study due to its shorter duration. As a sixth step, these anomalies in data were cleaned in order to guarantee the binary nature of sitting. Based on the cleaned data, an analysis of the sitting bouts was made as the seventh step. This analysis comprised the number of sitting bouts, the total duration of sitting, the average duration per sitting bout, and the duration of the longest sitting bout. These values can be found in the following section. When calculating the duration of sitting bouts, it was taken into consideration that adjustments of the sitting position in the instant of prompting the sensor could produce single readings that indicated no sitting. Thus, single readings of no sitting between continuous readings of sitting were interpreted not to interrupt sitting bouts. As the final step, the number of auditory notifications during the second week of both studies were calculated. Additionally, a pivot chart was prepared that gave an overview of the duration of sitting bouts by grouping them into five-minute intervals and displaying their relative occurrence. In order to facilitate comparison between the two weeks, another chart was created that contained data from both weeks. These charts can be found in the following section. The interviews with the participants were recorded, however not transcribed. Summarized findings from the interviews can also be found in the following section.

6.2.4 Results

Table 2 gives a distinct overview of the two weeks per participant. The table lists the number of sitting bouts, the total duration of sitting, the average duration per sitting bout, and the duration of the longest sitting bout. As the research focus was to evaluate the changes in duration of sitting bouts due to the auditory notifications, two charts display the duration of sitting bouts in five-minute intervals and compare their relative occurrence with and without the auditory notification for each participant (Figures 15 and 16). From the collected data, it would have been possible to analyze breaks and their duration as well. However, no conclusions can be drawn from this data, as the reasons for taking breaks from sitting on the office chair vary. For example, such breaks can occur due to meetings, lunch breaks, and toilet breaks.

Participant	Number of sitting bouts	Total duration of sitting (in minutes)	Average duration per sitting bout (in minutes)	Duration of the longest sitting bout (in minutes)	Number of notifications played
First week / Control week: without sound notification					
P1	42	1063	25	150	-
P2	19	1126	59	155	-
Second week / Intervention week: with sound notification					
P1	64	1142	18	88	18
P2	26	1259	48	175	41

Table 2: Overview of sedentary behavior

For P1, a large difference in the number of sitting bouts can be observed between the weeks with 52 percent more sitting bouts during the second week. While a similar trend can be observed in the total duration of sitting, it is less prominent with seven percent more sitting during the second week. The total duration of sitting equals 17.72 hours during the first and 19.03 hours during the second week. As a result, the average duration per sitting bout is seven minutes shorter during the second week with 18 minutes. Furthermore, the longest sitting bout during the second week is considerably shorter with 88 minutes compared to 150 minutes during the first week. Missing data due to power disruption of the sitting pad was 28 minutes during the first week and 5 minutes during the second week. Compared to the total duration of sitting of 1063 and 1142 minutes respectively, this amount of missing data does not question the overall results.

For P2, the total duration of sitting is twelve percent more during the second week with 20.98 hours compared to 18.77 hours during the first one. Furthermore, the participant accumulated 19 sitting bouts during the first and 26 sitting bouts during the second week. As a result, the average duration per sitting bout decreased from 59 minutes to 48 minutes in the second week. However, the longest sitting bout during the second week was 20 minutes longer compared to the 155-minute long sitting bout during the first week. No power disruption of the sitting pad was observed for either week and thus the amount of missing data equals zero.

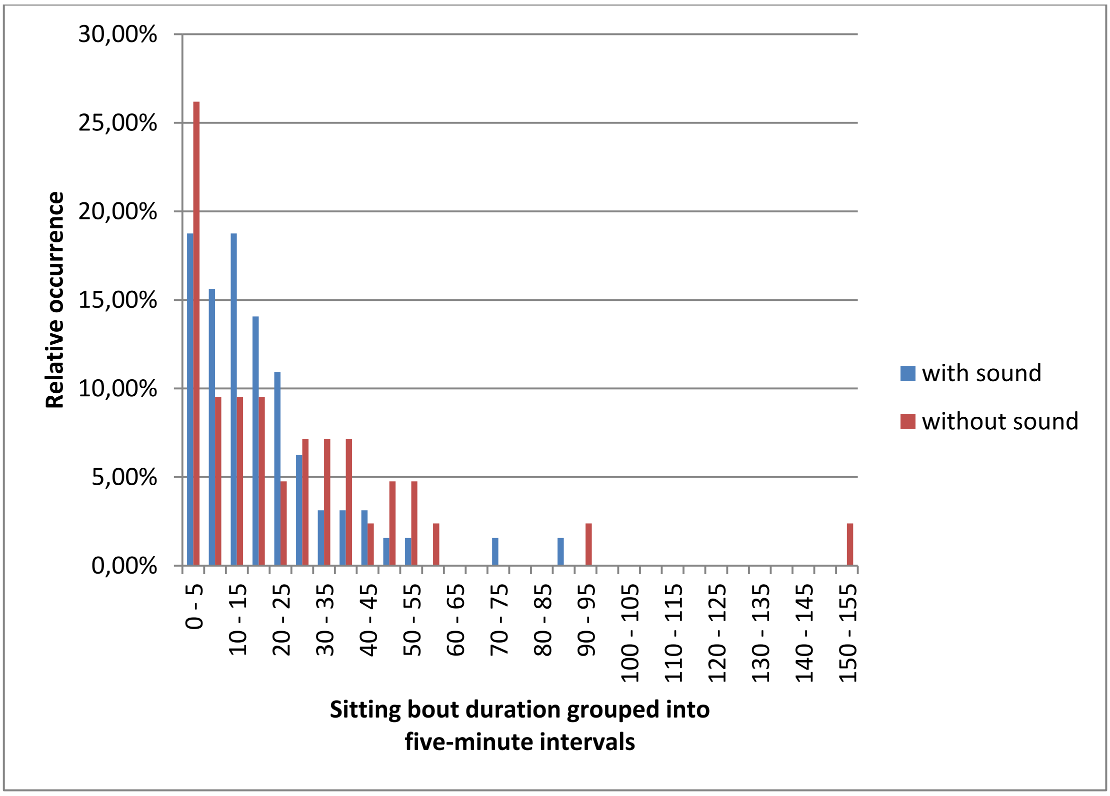

Figure 15: Intervals of sitting bout duration (in minutes) and their relative occurrences (in percent) of P1

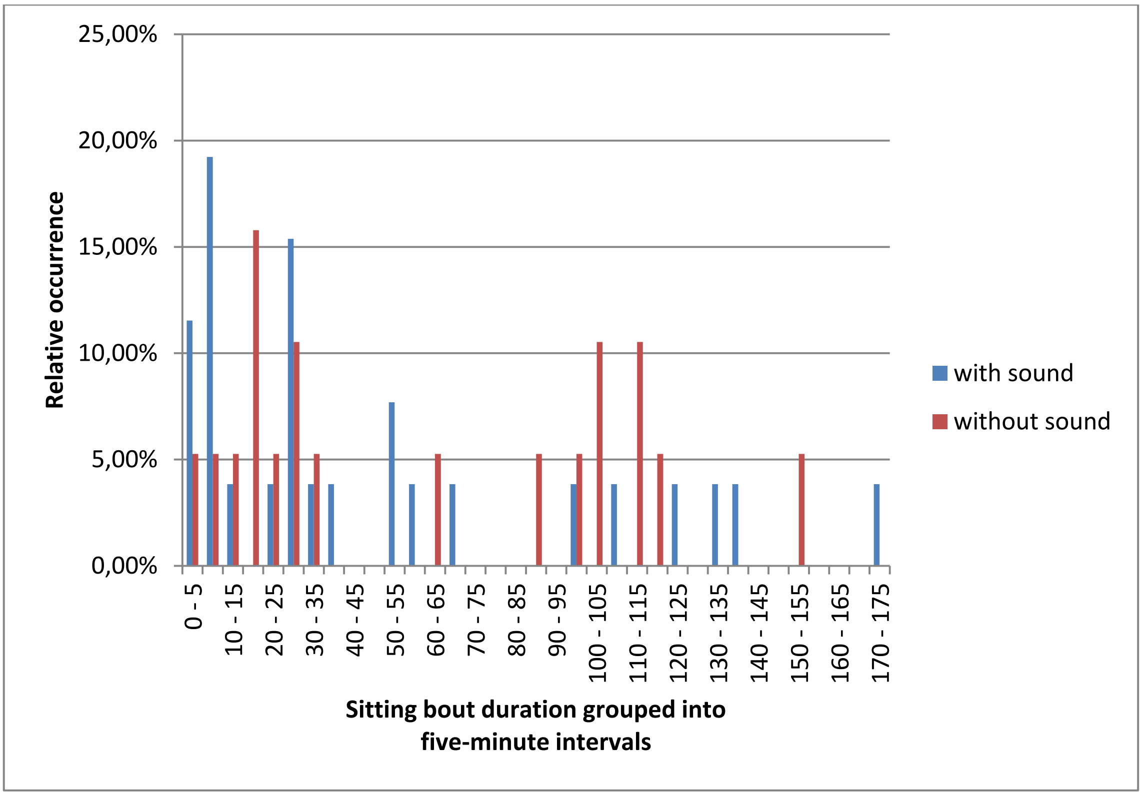

Figure 16: Intervals of sitting bout duration (in minutes) and their relative occurrences (in percent) of P2

Figures 15 and 16 provide a detailed overview of the duration of sitting bouts. The relative occurrence is used as the number of sitting bouts between the weeks varies naturally. Thus, employing absolute figures would draw a distorted picture. When comparing the two figures and thus the two participants, it is obvious that their sedentary behavior varies greatly. While P1 has a tendency to collect short bouts of sitting (< 60 minutes), P2 does not show such behavior and has a tendency to collect also long sitting bouts. Likewise, this is reflected in the number of notifications played as presented in Table 2. While P1 only received 18 notifications from the sitting pad during the intervention week, P2 received 41. This is remarkable as their total duration of sitting differed only slightly with 1142 (P1) and 1259 minutes (P2). As Figure 15 shows, P1 already shows a tendency to sit less than one hour at a time during the control week. Still, the duration of sitting bouts decreases in the intervention week. During the intervention week, 78 percent of all sitting bouts are shorter than 25 minutes. During the control week, it is only 60 percent. As depicted in Figure 16, P2 has a tendency to collect both long and short sitting bouts during control and intervention weeks. 38 percent of all sitting bouts are shorter than 25 minutes during intervention week compared to 37 percent during control week. Thus, there is no substantial difference in the occurrence of sitting bouts shorter than 25 minutes for P2. Table 3 provides a compact overview of these values. Furthermore, the changes in the occurrence of sitting bouts between 25 and 30 minutes (>= 25 and < 30 minutes) are depicted because the sitting pad emits its notifications after 25 minutes of continuous sitting (compare Table 3). Between control and intervention periods, no substantial difference can be observed for P1, while the occurrence of such sitting bouts increased for P2 from 10.5 to 15.4 percent. In conclusion, the occurrence of sitting bouts shorter than 30 minutes increased by 17.7 percentage points (P1) and 6.5 percentage points (P2). While both participants show a larger amount of short sitting bouts (<30 minutes) during intervention week, it can only be suspected that this is due to the notifications played by the sitting pad. Two participants are not enough to draw definite conclusions on the matter.

	P1			P2		
	without sound	with sound	difference in percentage points	without sound	with sound	difference in percentage points
A: Relative occurrence of sitting bouts <25 minutes	59,52 %	78,13 %	18,61	36,84 %	38,46 %	1,62
B: Relative occurrence of sitting bouts >=25 minutes and <30 minutes	7,14 %	6,25 %	-0,89	10,53 %	15,38 %	4,85
A + B: Relative occurrence of sitting bouts <30 minutes	66,66 %	84,38 %	17,72	47,37 %	53,84 %	6,47

Table 3: Relative occurrences of sitting bouts

In the interview, P1 concluded that using the sitting pad was in general a good experience. It was considered helpful to have the reminders after 25 minutes. However, when “being into something”, the participant admitted avoiding to stand up. When asked whether it created a bad conscience to ignore the notification and not to stand up, the participant denied. In regards to the safety of using the device, the participant noted that only the cable between the chair and the laptop for power supply was problematic.

Thus, a couple of times it happened to the participant that the cable was detached when moving with the chair. The notification melody was considered suitable, however the participant wondered several times “what is going on”. The participant associated the melody with a ringing phone or with a person entering the room. In meeting situations, visitors to the office were sometimes surprised when the sound started playing. However, in most cases the visitors were already curious about the purpose of the sitting pad when they saw it. Furthermore, the participant noted that the sound notification was not perceived as an annoying interruption in meeting situations. Additionally, the volume of the notification was considered suitable as it could always be perceived. The participant could imagine using the sitting pad also for a longer period of time than two weeks. When asked whether it increased the amount of standing up, the participant was unsure. However, the participant claimed that in combination with a standing desk, the amount of standing up could be increased. The participant could imagine converting the desk into a standing desk after 25 minutes and continuing to work in a standing position. Thus, focused work would not be interrupted by breaks.

P2 stated in the interview that the sitting pad did not influence the comfort of the office chair negatively. When asked about the usefulness of the sitting pad, the participant noted that the notifications did not trigger standing up more. The participant explained the reason for this being the particular workweek with deadlines on multiple projects. Therefore, taking a break after each notification was not considered an option. This led to the suggestion that the nature of tasks could potentially influence the effectiveness of the sitting pad. Despite the perceived inability of the sitting pad to increase standing up, the participant stated that the notifications made aware of time passing and thus increased the awareness of his own productivity. Whether this resulted in increased productivity could not be answered however. Furthermore, the participant perceived the occurrence of notifications to be scarce. Thus, the participant concluded that interruptions from sitting occur already naturally on a regular basis during the workday. In regards to the safety of using the sitting pad, the only obvious drawback was the cable between the office chair and the laptop. The notification melody of the sitting pad was considered too long in the beginning, however the participant stated that it was easy to get used to it. In addition, the volume was considered suitable. Finally, the participant could imagine using the sitting pad for longer than the study duration of two weeks. However, the participant was unsure about the need to use it.

7 Discussion

This research employed reactive notifications as an intervention that targets sedentary behavior. It was found that participants increased the relative occurrence of sitting bouts shorter than 30 minutes by 17.7 and 6.5 percentage points. The occurrence of sitting bouts below or above a certain threshold (in this case 30 minutes) is commonly used to measure the effectiveness of interventions on sedentary behavior (Evans et al., 2012; Healy et al., 2013; Neuhaus et al., 2014). However, Gilson et al. (2016), who used the sitting pad together with reactive notifications on a computer screen, did not employ these measures and focused instead on physical activity levels and total sitting time. In their study, it was possible to analyze physical activity levels due to the use of accelerometers. In the context of this research, using the total sitting time recorded by the sitting pad would have been misleading as the sitting pad was fixed to the office chair and thus did not record sitting time for example in meeting rooms. Due to the use of such different parameters, it was not possible to compare the findings despite the otherwise similar nature of the studies.

A limitation of the study was its short intervention period and the small number of participants. This does not allow the findings to be generalized and no conclusions can be drawn about the long-term effects. Strengths of the study were the objective measurement of sedentary behavior and the use of reactive notifications that functioned as a standalone solution.

Previous research on interventions that target sedentary behavior has demonstrated a decline in compliance with the intervention goals the longer the duration of the study (Karakolis & Callaghan, 2014, p. 799). This is likely to occur also in this context. Furthermore, the small number of participants does not enable to draw definite conclusions from these results. Despite this shortcoming, an interpretation of results is attempted. In this context, the occurrence of sitting bouts of various lengths can offer interesting insights. When analyzing the change in the occurrence of sitting bouts shorter than 30 minutes, a difference between the participants could be observed. While P1 was able to increase the occurrence of such sitting bouts by almost 18 percentage points, P2 only achieved around 6 percentage points. When analyzing the occurrence of sitting bouts shorter than 25 minutes, P1 reached an increase of 18.6 percentage points. On the other hand, P2 showed an increase of a mere 1.6 percentage points. Thus, P1 increased mainly the occurrence of sitting bouts shorter than 25 minutes, while P2 increased mainly the occurrence of sitting bouts between 25 and 30 minutes (Figures 15 and 16). The behavior change of P2 could possibly be attributed directly to the sitting pad as notifications were played after 25 minutes of continuous sitting. The behavior change of P1, on the other hand, might have derived from increased awareness of sitting patterns in general. Thus, P1 might not have relied on the notifications and instead might have stood up based on self-determination. Consequently, the sitting pad could have beneficial effects on sedentary behavior apart from its notifications. However, these findings are speculative and would have to be confirmed by increasing the number of study participants.

There are several limitations regarding the developed sitting pad. While the original idea was to develop a device that could be transferred easily, this could not be achieved due to technical difficulties in powering the sitting pad that required a cable to the device. Further research should thus consider making the sitting pad a movable device in order to be suitable for changing work locations. While this does not imply that the sitting pad is taken to each meeting for example, it would contribute to the usability and the safety of the device. Another limitation of the sitting pad is that its sensor recorded sitting through proximity. This occasionally resulted in rare, unclear data that could not be interpreted in an automated manner to represent sitting or no sitting. While this behavior did not question the overall validity of the sitting pad due to the rare occurrence and the possibility to analyze the data manually, the sensor should be improved in this regard.

Furthermore, a number of additional aspects should be considered as part of further research in this field. A reminder function could be implemented and evaluated, which repeats the notification after certain duration if the user of the sitting pad fails to stand up after the initial notification. Such a reminder could repeat the notification e.g. after one minute or after five minutes. Additionally, it might offer interesting insights to modify the notification interval of currently 25 minutes. However, it is likely not helpful to shorten the interval in order to avoid a disturbance to the user. Instead, longer intervals could be evaluated in regards to compliance and disturbance. Furthermore, the user could be given the possibility to self-determine the notification interval. Additionally, it could be tried to alter the melody and the volume of the notification. For example, nature sounds such as bird sounds or the sound of waves at the seaside could be incorporated with the possible effect to decrease stress levels.

One inherent limitation of the sitting pad is the insensitivity of its notification function. While the notifications are adaptive to the sitting behavior of the user and do not play at all when avoiding periods of sitting longer than 25 minutes, it must be noted that they are not context sensitive. This means that the notifications are not able to take into consideration whether it is a suitable time to take a break after 25 minutes. For example, a task might take another minute to complete and therefore the notification could be perceived as a disturbance to the user. As a solution, it should be considered to couple the sitting pad with ambient feedback such as an LED light that gradually changes color based on the sitting duration. This can raise awareness of the sitting duration while leaving the decision when to take a break to the person (Renfree & Cox, 2016). As suggested by one of the study participants in the interview, it would furthermore be interesting to use the sitting pad as part of a multi-component intervention, e.g. in conjunction with a standing desk.

8 Conclusion

This research successfully implemented the sitting pad, a device that can be placed on an office chair in order to remind its users to avoid long periods of uninterrupted sitting. For this reason, the sitting pad emits auditory notifications after 25 minutes of continuous sitting. The idea of the sitting pad was derived from previous research by Ryde et al. (2012) and Gilson et al. (2016). Effects of the device on the duration of sitting bouts were studied with two participants. This entailed comparing the occurrence of sitting bouts shorter than 30 minutes between a control and intervention period of one week each. Based on the occurrence of sitting bouts shorter than 30 minutes, it can be concluded that the sitting pad is effective in influencing sedentary behavior. However, in order to draw definite conclusions, the number of study participants would have to be increased. Due to the different setup of previous research that evaluated the effectiveness of reactive prompts on sedentary behavior (Gilson et al., 2016), the results could not be compared. Still, the implementation of this device has added to the variety of interventions that target sedentary behavior. Further research could evaluate the developed sitting pad as part of a multi-component intervention that targets changes in sedentary behavior.

References

Abrahamsson, P., Baskerville, R., Conboy, K., Fitzgerald, B., Morgan, L., & Wang, X. (2008). *Agile Processes in Software Engineering and Extreme Programming: 9th International Conference, XP 2008, Limerick, Ireland, June 10-14, 2008, Proceedings*. Springer Science & Business Media.

Alkhajah, T. A., Reeves, M. M., Eakin, E. G., Winkler, E. A. H., Owen, N., & Healy, G. N. (2012). Sit–Stand Workstations: A Pilot Intervention to Reduce Office Sitting Time. *American Journal of Preventive Medicine*, *43*(3), 298–303. https://doi.org/10.1016/j.amepre.2012.05.027

Archer, E., Shook, R. P., Thomas, D. M., Church, T. S., Katzmarzyk, P. T., Hébert, J. R., … Blair, S. N. (2013). 45-Year Trends in Women's Use of Time and Household Management Energy Expenditure. *PLOS ONE*, *8*(2), e56620. https://doi.org/10.1371/journal.pone.0056620

Atkin, A. J., Gorely, T., Clemes, S. A., Yates, T., Edwardson, C., Brage, S., … Biddle, S. J. (2012). Methods of Measurement in Epidemiology: Sedentary Behaviour. *International Journal of Epidemiology*, *41*(5), 1460–1471. https://doi.org/10.1093/ije/dys118

Badamasi, Y. A. (2014). The Working Principle of an Arduino. In *Electronics, Computer and Computation (ICECCO), 2014 11th International Conference on* (pp. 1–4). IEEE. Retrieved from http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=6997578

Badger, P. (n.d.). Arduino Playground - CapacitiveSensor. Retrieved September 12, 2016, from http://playground.arduino.cc/Main/CapacitiveSensor?from=Main.CapSense

Bauman, A., Ainsworth, B. E., Sallis, J. F., Hagströmer, M., Craig, C. L., Bull, F. C., … Sjöström, M. (2011). The Descriptive Epidemiology of Sitting: A 20-Country Comparison Using the International Physical Activity Questionnaire (IPAQ). *American Journal of Preventive Medicine*, *41*(2), 228–235. https://doi.org/10.1016/j.amepre.2011.05.003

Blaxter, L., Hughes, C., & Tight, M. (2010). *How To Research*. McGraw-Hill Education (UK).

Buckley, J. P., Hedge, A., Yates, T., Copeland, R. J., Loosemore, M., Hamer, M., … Dunstan, D. W. (2015). The Sedentary Office: an Expert Statement on the Growing Case for Change towards Better Health and Productivity. *British Journal of Sports Medicine*, *49*(21), 1357–1362. https://doi.org/10.1136/bjsports-2015-094618

Caspersen, C. J., Powell, K. E., & Christenson, G. M. (1985). Physical Activity, Exercise, and Physical Fitness: Definitions and Distinctions for Health-related Research. *Public Health Reports*, *100*(2), 126–131.

Cavalheri, V., Straker, L., Gucciardi, D. F., Gardiner, P. A., & Hill, K. (2015). Changing Physical Activity and Sedentary Behaviour in People with COPD. *Respirology*. https://doi.org/10.1111/resp.12680

Chief Medical Officers. (2011). Start Active, Stay Active: A Report on Physical Activity for Health from the Four Home Countries' Chief Medical Officers. Retrieved from https://www.sportengland.org/media/2928/dh_128210.pdf

Cirillo, F. (2006). The Pomodoro Technique (The Pomodoro). *Agile Processes in Software Engineering and*, *54*(2). Retrieved from http://1cm1.neocities.org/1.pdf

Colley, R. C., Garriguet, D., Janssen, I., Craig, C. L., Clarke, J., & Tremblay, M. S. (2011). Physical Activity of Canadian Adults: Accelerometer Results from the 2007 to 2009 Canadian Health Measures Survey. *Health Reports*, *22*(1), 7–14. https://doi.org/10.1186/1479-5868-8-98

Conlon, C. (2016). *Productivity For Dummies*. John Wiley & Sons.

Darma Inc. (n.d.). Darma Inc. - Products. Retrieved September 1, 2016, from http://darma.co/Pages/Darma%20Inc.%20-%20Products.html

DeMattia, L., Lemont, L., & Meurer, L. (2007). Do Interventions to Limit Sedentary Behaviours Change Behaviour and Reduce Childhood Obesity? A Critical Review of the Literature. *Obesity Reviews*, *8*(1), 69–81. https://doi.org/10.1111/j.1467-789X.2006.00259.x

Evans, R. E., Fawole, H. O., Sheriff, S. A., Dall, P. M., Grant, P. M., & Ryan, C. G. (2012). Point-of-Choice Prompts to Reduce Sitting Time at Work: A Randomized Trial. *American Journal of Preventive Medicine*, *43*(3), 293–297. https://doi.org/10.1016/j.amepre.2012.05.010

Garber, C. E., Blissmer, B., Deschenes, M. R., Franklin, B. A., Lamonte, M. J., Lee, I.-M., … Swain, D. P. (2011). Quantity and Quality of Exercise for Developing and Maintaining Cardiorespiratory, Musculoskeletal, and Neuromotor Fitness in Apparently Healthy Adults: Guidance for Prescribing Exercise. *Medicine & Science in Sports & Exercise*, *43*(7), 1334–1359. https://doi.org/10.1249/MSS.0b013e318213fefb

Gilson, N. D., Ng, N., Pavey, T. G., Ryde, G. C., Straker, L., & Brown, W. J. (2016). Project Energise: Using Participatory Approaches and Real Time Computer Prompts to Reduce Occupational Sitting and Increase Work Time Physical Activity in Office Workers. *Journal of Science and Medicine in Sport*. https://doi.org/10.1016/j.jsams.2016.01.009

Gilson, N. D., Puig-Ribera, A., McKenna, J., Brown, W. J., Burton, N. W., & Cooke, C. B. (2009). Do Walking Strategies to Increase Physical Activity Reduce Reported Sitting in Workplaces: a Randomized Control Trial. *The International Journal of Behavioral Nutrition and Physical Activity*, *6*(43). https://doi.org/10.1186/1479-5868-6-43

Gilson, N. D., Suppini, A., Ryde, G. C., Brown, H. E., & Brown, W. J. (2012). Does the Use of Standing “Hot” Desks Change Sedentary Work Time in an Open Plan Office? *Preventive Medicine*, *54*(1), 65–67. https://doi.org/10.1016/j.ypmed.2011.10.012

Healy, G. N., Clark, B. K., Winkler, E. A. H., Gardiner, P. A., Brown, W. J., & Matthews, C. E. (2011). Measurement of Adults’ Sedentary Time in Population-Based Studies. *American Journal of Preventive Medicine*, *41*(2), 216–227. https://doi.org/10.1016/j.amepre.2011.05.005

Healy, G. N., Dunstan, D. W., Salmon, J., Cerin, E., Shaw, J. E., Zimmet, P. Z., & Owen, N. (2008). Breaks in Sedentary Time Beneficial Associations with Metabolic Risk. *Diabetes Care*, *31*(4), 661–666. https://doi.org/10.2337/dc07-2046

Healy, G. N., Eakin, E. G., LaMontagne, A. D., Owen, N., Winkler, E. A. H., Wiesner, G., … Dunstan, D. W. (2013). Reducing Sitting Time in Office Workers: Short-term Efficacy of a Multicomponent Intervention. *Preventive Medicine*, *57*(1), 43–48. https://doi.org/10.1016/j.ypmed.2013.04.004

Hines, S. (2010). *Productivity for Librarians: How to Get More Done in Less Time*. Elsevier.

Hu, J. (2016). Systems and Methods for Posture and Vital Sign Monitoring. Retrieved from http://www.freepatentsonline.com/y2016/0089059.html

Joppe, M. (2000). *The Research Process*. Retrieved from http://scholar.google.com/scholar?cluster=13771429504795563452

Karakolis, T., & Callaghan, J. P. (2014). The Impact of Sit–Stand Office Workstations on Worker Discomfort and Productivity: A Review. *Applied Ergonomics*, *45*(3), 799–806. https://doi.org/10.1016/j.apergo.2013.10.001

Kickstarter. (n.d.). Darma: Sit Smart for a Healthy Body and Mind. Retrieved September 1, 2016, from https://www.kickstarter.com/projects/junhao/darma-sit-smart-for-a-healthy-body-and-mind

Lazar, D. J., Feng, D. J. H., & Hochheiser, D. H. (2010). *Research Methods in Human-Computer Interaction*. John Wiley & Sons.

Marshall, S. J., & Ramirez, E. (2011). Reducing Sedentary Behavior A New Paradigm in Physical Activity Promotion. *American Journal of Lifestyle Medicine*, *5*(6), 518–530. https://doi.org/10.1177/1559827610395487

Martin, A., Fitzsimons, C., Jepson, R., Saunders, D. H., Ploeg, H. P. van der, Teixeira, P. J., … Mutrie, N. (2015). Interventions with Potential to Reduce Sedentary Time in Adults: Systematic Review and Meta-analysis. *British Journal of Sports Medicine*, *49*(16), 1056–1063. https://doi.org/10.1136/bjsports-2014-094524

Matthews, C. E., George, S. M., Moore, S. C., Bowles, H. R., Blair, A., Park, Y., … Schatzkin, A. (2012). Amount of Time Spent in Sedentary Behaviors and Cause-specific Mortality in US Adults. *The American Journal of Clinical Nutrition*, *95*(2), 437–445. https://doi.org/10.3945/ajcn.111.019620

Messing, K., Stock, S., Côté, J., & Tissot, F. (2015). Is Sitting Worse Than Static Standing? How a Gender Analysis Can Move Us Toward Understanding Determinants and Effects of Occupational Standing and Walking. *Journal of Occupational and Environmental Hygiene*, *12*(3), D11–D17. https://doi.org/10.1080/15459624.2014.987388

Michie, S., van Stralen, M. M., & West, R. (2011). The Behaviour Change Wheel: a New Method for Characterising and Designing Behaviour Change Interventions. *Implementation Science*, *6*(42). Retrieved from http://www.implementationscience.com/content/6/1/42/

Neuhaus, M., Healy, G. N., Dunstan, D. W., Owen, N., & Eakin, E. G. (2014). Workplace Sitting and Height-Adjustable Workstations: A Randomized Controlled Trial. *American Journal of Preventive Medicine*, *46*(1), 30–40. https://doi.org/10.1016/j.amepre.2013.09.009

Owen, N. (2012). Sedentary behavior: Understanding and Influencing Adults' Prolonged Sitting Time. *Preventive Medicine*, *55*(6), 535–539. https://doi.org/10.1016/j.ypmed.2012.08.024

Owen, N., Leslie, E., Salmon, J., & Fotheringham, M. J. (2000). Environmental Determinants of Physical Activity and Sedentary Behavior. *Exercise and Sport Sciences Reviews*, *28*(4), 153–158.

Pate, R. R., O'Neill, J. R., & Lobelo, F. (2008). The Evolving Definition of" Sedentary." *Exercise and Sport Sciences Reviews*, *36*(4), 173–178.

Polit, D. F., Beck, C., & Hungler, B. P. (2001). *Essentials of Nursing Research: Methods, Appraisal, and Utilization 5th ed* (5th Revised edition edition). Philadelphia: Lippincott Williams and Wilkins.

Proper, K. I., Singh, A. S., van Mechelen, W., & Chinapaw, M. J. M. (2011). Sedentary Behaviors and Health Outcomes Among Adults. *American Journal of Preventive Medicine*, *40*(2), 174–182. https://doi.org/10.1016/j.amepre.2010.10.015

Renfree, I. M., & Cox, A. (2016). Tangibly Reducing Sedentariness in Office Workers. Retrieved from http://discovery.ucl.ac.uk/1477628/

Rosenberg, D. E., Bull, F. C., Marshall, A. L., Sallis, J. F., & Bauman, A. E. (2008). Assessment of Sedentary Behavior with the International Physical Activity Questionnaire. *Journal of Physical Activity & Health*, *5*(S1), 30–44.

Ryde, G. C., Gilson, N. D., Suppini, A., & Brown, W. J. (2012). Validation of a Novel, Objective Measure of Occupational Sitting. *Journal of Occupational Health*, *54*(5), 383–386.

Sallis, J. F., Owen, N., & Fotheringham, M. J. (2000). Behavioral Epidemiology: a Systematic Framework to Classify Phases of Research on Health Promotion and Disease Prevention. *Annals of Behavioral Medicine*, *22*(4), 294–298.

Šekoranja, B., Bašić, D., Švaco, M., Šuligoj, F., & Jerbić, B. (2014). Human-Robot Interaction Based on Use of Capacitive Sensors. *Procedia Engineering*, *69*, 464–468. https://doi.org/10.1016/j.proeng.2014.03.013

Smith, A. L., & Biddle, S. (2008). *Youth Physical Activity and Sedentary Behavior: Challenges and Solutions*. Human Kinetics. Retrieved from https://books.google.fi/books?id=NEeCUaqoAWYC

Straker, L., Abbott, R. A., Heiden, M., Mathiassen, S. E., & Toomingas, A. (2013). Sit–Stand Desks in Call Centres: Associations of Use and Ergonomics Awareness with Sedentary Behavior. *Applied Ergonomics*, *44*(4), 517–522. https://doi.org/10.1016/j.apergo.2012.11.001

Thorp, A. A., Kingwell, B. A., Owen, N., & Dunstan, D. W. (2014). Breaking up Workplace Sitting Time with Intermittent Standing Bouts Improves Fatigue and Musculoskeletal Discomfort in Overweight/Obese Office Workers. *Occupational and Environmental Medicine*, *71*(11), 765–771. https://doi.org/10.1136/oemed-2014-102348

Townsend, N., Bhatnagar, P., Wickramasinghe, K., Scarborough, P., Foster, C., & Rayner, M. (2012). Physical Activity Statistics 2012. British Heart Foundation, London. Retrieved from https://www.bhf.org.uk/-/media/files/research/heart-statistics/m130-bhf_physical-activity-supplement_2012.pdf

Van der Ploeg, H. P., Chey, T., Korda, R. J., Banks, E., & Bauman, A. (2012). Sitting Time and All-cause Mortality Risk in 222 497 Australian Adults. *Archives of Internal Medicine*, *172*(6), 494–500.

Van Teijlingen, E. R., & Hundley, V. (2010). The Importance of Pilot Studies. *Social Research Update*, *35*, 49–59.

van Uffelen, J. G. Z., Wong, J., Chau, J. Y., van der Ploeg, H. P., Riphagen, I., Gilson, N. D., … Brown, W. J. (2010). Occupational Sitting and Health Risks: A Systematic Review. *American Journal of Preventive Medicine*, *39*(4), 379–388. https://doi.org/10.1016/j.amepre.2010.05.024

Wilks, S., Mortimer, M., & Nylén, P. (2006). The Introduction of Sit–Stand Worktables; Aspects of Attitudes, Compliance and Satisfaction. *Applied Ergonomics*, *37*(3), 359–365. https://doi.org/10.1016/j.apergo.2005.06.007

World Health Organization. (2009). *Global Health Risks: Mortality and Burden of Disease Attributable to Selected Major Risks*. World Health Organization. Retrieved from http://www.who.int/healthinfo/global_burden_disease/GlobalHealthRisks_report_full.pdf

Appendices

Appendix 1: Pilot Study 1 - Informed Consent Form

Pilot Study 1: Informed Consent Form

Purpose

The purpose of this pilot study is to establish the validity and reliability of the sitting pad. This is to confirm whether the data recorded by the sitting pad corresponds to the real-life sedentary state (sitting or not sitting) and whether the data is consistent over time.

Description of procedure

The sitting pad consists of the sensor unit and its microcontroller unit that are set up on the office chair. The sensor covers the seat surface of the chair, while the microcontroller unit is contained in a plastic case, which is attached to the backside of the backrest with a strap. A cable connects both the sensor unit with the microcontroller unit and the microcontroller unit with a laptop. The connection to the laptop serves as power source and to transmit data. Every five seconds the program on the microcontroller unit queries the sensor unit and produces a numeric value, which represents the sedentary state (sitting or not sitting). Together with a timestamp, this value is sent to the connected laptop and displayed in a separate window. Next to the this window, a camera image from the built-in webcam is displayed. A self-developed program takes a screenshot of the whole screen whenever data is sent to the laptop. From the screenshot, it is thus possible to compare the value recorded by the sitting pad to the real-life sedentary state. As a result, the readings can match each other or not.

The pilot study is conducted throughout one full workday. The collected data is handled anonymously. In the thesis, the gender, weight class (in 10 kg steps) and height class (in 10 cm steps) of the participant are published. With explicit permission, some of the screenshots could be included. The participant is free to stop participating in the pilot study at any time.

Reward

Participation in this pilot study is much appreciated, however no financial reward is paid for participation.

Risks

The USB cable between the laptop and the microcontroller unit can potentially pose a risk of tripping. In order to minimize this risk a USB extension cord is used. In case the test participant trips over the cable, the connection between the USB extension cord and the USB cable becomes detached, which prevents injuries.

Consent

I have read and understood this document and decided to participate in the pilot study.

Date and place	Signature researcher	Signature participant

Appendix 2: Pilot Study 1 Addition - Informed Consent Form

Pilot Study 1 - Addition: Informed Consent Form

Purpose

The purpose of this pilot study is to establish the validity and reliability of the sitting pad. This is to confirm whether the data recorded by the sitting pad corresponds to the real-life sedentary state (sitting or not sitting) and whether the data is consistent over time.

Description of procedure

The sitting pad consists of the sensor unit and its microcontroller unit that are set up on the office chair. The sensor covers the seat surface of the chair, while the microcontroller unit is contained in a plastic case, which is attached to the backside of the backrest with a strap. A cable connects both the sensor unit with the microcontroller unit and the microcontroller unit with a laptop. The connection to the laptop serves as power source and to transmit data. Every five seconds the program on the microcontroller unit queries the sensor unit and produces a numeric value, which represents the sedentary state (sitting or not sitting). Together with a timestamp, this value is sent to the connected laptop and displayed in a separate window. Next to the this window, a camera image from the built-in webcam is displayed. A self-developed program takes a screenshot of the whole screen whenever data is sent to the laptop. From the screenshot, it is thus possible to compare the value recorded by the sitting pad to the real-life sedentary state. As a result, the readings can match each other or not.

The pilot study takes about ten minutes to complete. The participant is free to stop participating in the pilot study at any time.

The participant is asked to sit down, remain seated for about 30 seconds, then stand up and remain standing for the same duration. This procedure is repeated three times and the participant is asked to sit on the chair in a different posture each time. The posture can be decided by the participant. The collected data is handled anonymously. In the thesis, the gender, weight class (in 10 kg steps) and height class (in 10 cm steps) of the participant are published.

Reward

Participation in this pilot study is much appreciated, however no financial reward is paid for participation.

Risks

The USB cable between the laptop and the microcontroller unit can potentially pose a risk of tripping. In order to minimize this risk a USB extension cord is used. In case the test participant trips over the cable, the connection between the USB extension cord and the USB cable becomes detached, which prevents injuries.

Consent

I have read and understood this document and decided to participate in the pilot study.

Date and place	Signature researcher	Signature participant

Appendix 3: Pilot Study 2 - Informed Consent Form

Pilot Study 2: Informed Consent Form

Purpose

The purpose of this pilot study is to evaluate the feasibility of research techniques and methods, which are to be used for evaluating the sitting pad.

Description of procedure

The sitting pad consists of the sensor unit and its microcontroller unit that are set up on the office chair. The sensor covers the seat surface of the chair, while the microcontroller unit is contained in a plastic case, which is attached to the backside of the backrest with a strap. A cable connects both the sensor unit with the microcontroller unit and the microcontroller unit with a laptop. The connection to the laptop serves as power source only. Every five seconds the program on the microcontroller unit queries the sensor unit and produces a numeric value, which represents the sedentary state (sitting or not sitting). Together with a timestamp, this value is stored on a SD memory card in the microcontroller unit.

When sitting is detected, a timer is started. After 25 minutes of continuous sitting, a sound is played. If the sitting continues after this event, the timer is automatically restarted. The timer is configured to be deactivated when no sitting is detected for more than one query interval of five seconds. Thus, it allows for very short sitting interruptions such as readjusting the sitting position.

The pilot study is conducted throughout one full workday. The participant is free to stop participating in the pilot study at any time. The participant is asked not to wear headphones or play loud music during the pilot study. After the pilot study, an interview is conducted. The collected data is handled anonymously. In the thesis, the gender, weight class (in 10 kg steps) and height class (in 10 cm steps) of the participant are published.

Reward

Participation in this pilot study is much appreciated, however no financial reward is paid for participation in the pilot study.

Risks

The USB cable between the laptop and the microcontroller unit can potentially pose a risk of tripping. In order to minimize this risk a USB extension cord is used. In case the test participant trips over the cable, the connection between the USB extension cord and the USB cable becomes detached, which prevents injuries.

Consent

I have read and understood this document and decided to participate in the pilot study.

Date and place	Signature researcher	Signature participant

Appendix 4: Pilot Study 2 - Interview Questions

Pilot Study 2: Interview Questions

How pleasant is it to sit on the sitting pad?

How useful do you consider the usage of the sitting pad?

How safe do you consider the usage of the sitting pad?

How suitable is the volume of the sound notification?

How pleasant is the sound notification?

Could you imagine using the sitting pad for a period of two weeks? If no, why?

Could you imagine using the sitting pad for a period of longer than two weeks? If no, why?

Do you have any comments, remarks, suggestions?

Appendix 5: User Study - Informed Consent Form

User Study: Informed Consent Form

Purpose

The purpose of this user study is to evaluate the effect of an auditory (sound) notification on sedentary behavior using the sitting pad.

Description of procedure

The sitting pad consists of the sensor unit and its microcontroller unit that are set up on the office chair. The sensor covers the seat surface of the chair, while the microcontroller unit is contained in a plastic case, which is attached to the backside of the backrest with a strap. A cable connects both the sensor unit with the microcontroller unit and the microcontroller unit with a laptop. The connection to the laptop serves as power source only. Every five seconds the program on the microcontroller unit queries the sensor unit and produces a numeric value, which represents the sedentary state (sitting or not sitting). Together with a timestamp, this value is stored on an SD memory card in the microcontroller unit for later analysis of the sitting behavior.

The user study takes two weeks. It can start at any day of the week, depending on the availability of the participant. During the first week, the sitting pad only collects data as described above. The data collection continues also during the second week and the following functionality is added: When sitting is detected, a timer is started. After 25 minutes of continuous sitting, a sound is played. If the sitting continues after this event, the timer is automatically restarted and would thus play another sound after 25 minutes, if the sitting continues for this long. The timer is configured to be deactivated when no sitting is detected for more than one query interval of five seconds. Thus, it allows for very short sitting interruptions such as readjusting the sitting position. The participant is asked not to wear headphones or play loud music during the second week of the user test. After the second week of the user study, an interview is conducted. The participant is free to stop participating in the pilot study at any time. The collected data is handled anonymously. In the thesis, the gender, weight class (in 10 kg steps) and height class (in 10 cm steps) of the participant are published.

Reward

Participation in this pilot study is much appreciated, however no financial reward is paid for participation in the user study.

Risks

The USB cable between the laptop and the microcontroller unit can potentially pose a risk of tripping. In order to minimize this risk a USB extension cord is used. In case the test participant trips over the cable, the connection between the USB extension cord and the USB cable becomes detached, which prevents injuries.

Consent

I have read and understood this document and decided to participate in the pilot study.

Date and place	Signature researcher	Signature participant

Appendix 6: User Study – Questionnaire

Sitting pad user study: Questionnaire

1. **I think that prolonged sitting has negative health effects.**
   Mark only one oval.

	1	2	3	4	5	
Strongly agree	◯	◯	◯	◯	◯	Strongly disagree

2. **I sit too much during the working day.**
   Mark only one oval.

	1	2	3	4	5	
Strongly agree	◯	◯	◯	◯	◯	Strongly disagree

3. **I easily forget about time when working on something.**
   Mark only one oval.

	1	2	3	4	5	
Strongly agree	◯	◯	◯	◯	◯	Strongly disagree

4. **I easily forget to take breaks during the working day.**
   Mark only one oval.

	1	2	3	4	5	
Strongly agree	◯	◯	◯	◯	◯	Strongly disagree

5. **Do you sometimes work in a standing position?**
   Mark only one oval.

   ◯ Yes
   ◯ No

6. **Can your desk be converted into a standing desk?**
   Mark only one oval.

   ◯ Yes
   ◯ No

7. **How many hours per week do you spend working in your office seated at your desk (estimated)?**

   ____

8. **How many hours per week do you spend seated in meetings, classes, and seminars (estimated)?**

   ____

Appendix 7: User Study – Interview Questions

User Study: Interview Questions

How pleasant is it to sit on the sitting pad?

How useful do you consider the usage of the sitting pad?

How safe do you consider the usage of the sitting pad?

How suitable is the volume of the sound notification?

How pleasant is the sound notification?

Could you imagine using the sitting pad for a period of longer than two weeks? If no, why?

Do you have any comments, remarks, suggestions?